Chapter 2
The Owls and the Gufo. Birth of Italian Radar

Sous les ifs noir qui les abritent,
Les hiboux se tiennent rangés
Ainsi que des dieux étrangers,
Dardant leur oeil rouge. Ils méditent.

Charles Baudelaire

2.1 The Owls of Charles Baudelaire and the *Gufo* by Ugo Tiberio

The Owls, disturbing and mysterious appearances at night, for many centuries, since the classical age, have inspired many authors, in particular poets such as Baudelaire[1] who considers the Owls as witnesses of a meditative life whose imperative is "the fear of the tumult and of the movement" (*Qu'il faut en ce monde qu'il craigne/Le tumulte et le mouvenent*). From the second line of verse it is clear that the poet—an acute observer—noticed the habit (the only one amongst all nocturnal predator birds) for which in winter the Owls spend their days perched in a row on the same tree from which they go hunting in the evening. Baudelaire was also impressed by the fixedness and apparent depth of their gaze.[1] Very appropriately, a considerable Italian gave the name of *Gufo* to the radar he conceived and realized in the form of a working prototype.

The naval radar was the only means, used by the British and the Germans during the Second World War, which made naval combat possible at night. As explained below, none can claim the full and absolute paternity of any complex and significant invention, much less of radar; however, because of his studies and his achievements, Ugo Tiberio[2] is universally known as the *father of Italian*

[1]Charles Baudelaire (1821–1867), "Les Fleurs du Mal", No. 67—*Les Hiboux*, first strophe.

G. Galati, *100 Years of Radar*, DOI 10.1007/978-3-319-00584-3_2



Fig. 2.1 The postcard printed for the commemoration day of Ugo Tiberio, October 24th, 1998

radar. He was commemorated on October 24th, 1998 at the University of his native city, Campobasso [SMM 98]. The postcard produced on that occasion is shown in Fig. 2.1. The first Italian naval radar, designed and implemented by Tiberio, subsequently became a series produced by industry with the name of *Gufo* (this name, most likely due to Tiberio himself, dates back to 1941).[2]

In this frame the best introduction to the *Gufo* in particular and to the surface and airborne radar in general can be found in the words written by Ugo Tiberio in 1936, in the so-called "Found Manuscript" following another (unfortunately lost) document which is considered to have been written by Tiberio in 1935. This 29-pages document handwritten by Tiberio and classified "Secret" is faithfully reported here (in a literal translation) in its main parts (some parts are omitted for the sake of brevity) in the "Annex" that follows. This manuscript was found by Paolo and Roberto, sons of Ugo Tiberio, in 1996 in their father's home in Livorno:

[2] Commemoration Day in Campobasso has included participation by the sons of Ugo Tiberio, Paolo and Roberto, by many representatives of the Italian Navy (MMI) and in particular of the RIEC (Mariteleradar), as well as by representatives from academia and from the main national industries active in radar.

it was abandoned in a large case locked for a long time. It is reproduced in [SMM 98] both in photocopy and in a—not perfect—typewritten transcription.

2.2 Annex No. 1—The "Found Manuscript" by Ugo Tiberio, Livorno, 1936

Secret—Superior Military Institute for Transmissions—Ist Section
(Ing. Ugo Tiberio)

(a) Study on the possibility of using for military purposes the effects of reflection of ultra short wave.
(b) *Radiotelemetro* for night shooting from ship and aircraft, as well as for anti-aircraft shooting.

Summary: The possibility of using the effects of reflection that the ultra short waves undergo on obstacles is examined for the purposes of:

1° to detect, in open sea and in the context of the optical range, the presence of a ship invisible due to darkness or fog;
2° to measure the distance of the ship;
3° to determine its direction.

It is concluded that these three aims can be achieved, provided that the problem is appropriately set, and that it is possible to use the method even for the following other aims:

4° to refine (in visibility conditions) the measurement of the optical range finders on board of the ship;
5° to search aircraft;
6° to measure, from an airplane, its height above the ground;
7° to search a ship from an airplane for the purpose of torpedoing.

We describe two types of equipment suitable for this aim. We propose to perform an experimental research to ascertain whether, and to what extent, the theoretical deductions are true, and we indicate the method to be followed.

1° Foreword. The problem of night search of vessels and aircraft has been dealt with by infrared radiation, microwave and acoustic methods, with very poor results so far. The use of ultra short wave was not attempted, yet, because the effects of reflection from these waves did not appear, at a first sight, such as to enable their practical use. In fact the waves from a reflective obstacle such as a ship or an airplane go back to the transmitter with an intensity which is very small in comparison to that of the direct field in the immediate vicinity of the oscillator, so it is very difficult to detect them.

However, a careful examination of the question, and some data that I am collecting in the recent years, lead me to think that we can overcome this

difficulty and use the ultra short wave also in order to measure the distance to the reflecting obstacle and estimate its direction. This method is suited to many, important military applications. In what follows, however, I am referring mainly to naval search, for which I have more data and that I studied in a special way on the invitation of S. E. Admiral V. De Feo, who has followed from the beginning the progress of this work with keen interest.

2° Value of the field returned toward the transmitter from a ship or an airplane, due to the effect of re-radiation and reflection.

The problem of determining the backscattered field from a ship hit by ultra short wave seems to have never been considered by R. Marina [*Italian Navy*], nor there is any treatment of it in the technical literature; therefore I have been forced to make a rough estimate, on the basis of experimental measurements made by those who have been involved in similar issues. Luckily, I could rely on reliable data, collected in a study by Trevor and Carter regarding propagation of waves along the surface of the sea, and in one by Seiler regarding the real re-radiation and reflection. I have shown in the Appendix the calculations and the considerations that I assumed to derive the values related to our problem.

I have also tried to perform the calculations in a purely theoretical way, but I feel that it is useless to report in this regard, since the values deducted in this way are very high, and it is wise not to rely on them.

In the following table probable values are shown for the field backscattered to the transmitter, on the assumption that the latter operates on the 2 m wavelength with a directional antenna beam and radiates a power of 1000 W, parallel to the surface of the sea. These values are listed in relation to the distance of the reflecting unit and to the nature and location of it.

Distance (metres)	Vessel—side view	Vessell—front view	Aeroplane
1000			2400
2000			600
5000	36,000	4500	90
10,000	900	120	22
20,000	30	7	5
If the transmitter radiates 100 watt in circular polarization the above values become:			
1000			80
2000			20
5000	1,200	150	3
10,000	29	4	
20,000	1		

(The considered vessel is a 10,000 tons cruiserl—field intensities are in μV/m)

It results from these values that, at the distances of interest in naval operations, the field would still be able to be detected with ordinary receivers, if it does not overlap the field that comes directly to the receiver from the

transmitter, which is much more intense. In fact, with waves of the order of 2 m, it is difficult to prevent the direct field from reaching the receiver: in the best case, it is of the same order as that reflected, unless you strive with continuous reflectors of large size.

To overcome this drawback, microwave apparatuses ($\lambda = 18$ cm) have been proposed, in which they managed to achieve a directivity so perfect as to be sure that the receiver, in spite of being located close to the transmitter, receives the reflected field only. In this way a solution was reached; however it is not suitable, because the system has, for the given value of the wavelength, a small transmitted power, a poor sensitivity in reception, a limited field, a large size and the need for pointing, in such a way that little advantage is obtained with respect to the infrared optical devices.

I do believe that all of this depends on a poor statement of the problem. In fact, the reception of a weak field in the presence of a strong one remains virtually impossible until both fields have the same frequency, but, instead, it becomes extremely easy if the frequencies are different. From this observation results the principle that I expose here: "to take advantage of the time that the reflected wave employs in the return path to change the frequency of the transmitter". If the operation is such that, for example, the frequency deviation is of the acoustic order, the reflected signal can be detected by a simple beat with the direct one, as it happens in a common heterodyne telegraphic receiver. In this way, not only the direct field does not cause damage, but it is useful because it provides the necessary energy for "heterodyning" the reflection, and it is known that the reception, when takes place according to a scheme of this kind, assumes a sensitivity enormously greater than the ordinary telephone: for waves of the order of 20 m, 1 μV/m is enough for the commercial telegraph service. In the ultra short wave region, given the absence of interference, even less should suffice. It must be considered that in our case it is not to needed to receive telegraphy, but only to detect a constant hissing. In the ordinary telephony, on the other hand, we need fields of the order of 100 μV/m.

This observation makes the above tables of noticeable interest: in fact, it can be seen as, by using a transmitter power of 1 kW, it is perfectly possible to detect a cruiser, and even an airplane, at a distance of 20 km and beyond, and that a not much smaller distance can be reached on airplanes by transmitting 100 W with circular polarization. It is also interesting to note how the tables indicate an extremely rapid decrease of the reflected field as the distance increases, so that obstacles situated beyond the optical limit, such as the coastal mountains and the far out ships, do not backscatter energy in such a degree as to alter the detections.

If the intensity of the reflected fields, as calculated by me, are correct, it can be concluded that, <u>if the reception is made according to the heterodyne scheme, using the ultra short waves it is possible to determine the presence</u>

> of vessels and airplanes up to 20,000 m and beyond, i.e. to the distances that are of interest in naval tactics.

The Found Document proceeds with the following points, partly summarized here:

3° Principle of the *Radiotelemetro*

In this point Tiberio describes the possible waveforms to be used, substantially equal to that of a modern FMCW radar, i.e. in continuous wave (CW) frequency-modulated (FM) and the method for measuring the distance, which is proportional to the delay of the echo (according to the basic radar principle) by the factor (speed of light)/2, in practice 150 m for each microsecond of delay. Very wisely the 32-year-old Tiberio writes, with regard to the choice between the mechanical implementation and the electronic one (much more modern and his preferred) of the frequency modulation of the transmitted wave:

> The problem can be solved with artifices of the mechanical type (electrostatic microphones, capacitors kept in continuous motion) or of the electronic type (triodes that set on and off some reactive elements in the oscillatory circuit). In my preliminary report, presented to the Management of the Institute, I preferred an artifice of the electronic type, in order to avoid bodies in motion. But General Sacco has correctly observed that the mechanical solution, even though it may appear at a first sight quite critical, in fact is very simple and practical, and also has the advantage of an operating procedure more clear, while the one which I had preferred raises complicated questions relating to the theory of frequency modulation. On the other hand, it would be out of place to study complex schematics when the validity of the principle has still to be experimentally tested. It is therefore advisable to assign the electronic method to a possible second phase of the research, and to use, to vary the frequency, the system that, after all, is the simplest one: to rotate the capacitor of the oscillatory circuit. This method has already been used by the Radio Res. Board for the radio-atmospheric survey …

4° Schematic of the of the *Radiotelemetro*

Tiberio describes the detailed embodiment of the apparatus and suggests an experimental implementation for trials on coastal installation in the Institute (the RIEC, the Tiberio's Institute where he wished to do the trials, is on the coast of Tuscany):

To translate into practice the principle outlined above, is needed:

(a) a system of antennas;
(b) an ultra-short, frequency modulated wave oscillator;
(c) receivers;
(d) devices for measuring the frequencies.

Since the structure of these various elements should, in the case of mounting on a ship, be studied with special criteria that would complicate the description, for the sake of simplicity I prefer to refer to the experimental system that I propose to place on a coastal site for the execution of the preliminary tests. In the diagram enclosed here, these elements are marked with the same letters used to list them.

A description of the individual elements follows; it is noticeable the use of a single oscillator (with multiplications and divisions of its frequency) to generate both the transmitted frequency (Tiberio proposes a value of 100 MHz, i.e., a wave of 3 m, in the range of “ultra-short waves”) and the reference for the intermediate frequency conversion: a true coherent super-heterodyne transceiver, inherently little sensitive to any fluctuations in the base frequency. Tiberio concludes his report highlighting the need to measure the “re-radiation factor”, which we call today the “equivalent area” or “radar cross section” of the targets; having understood the difficulty to calibrate the radar, Tiberio correctly proposes to compare the measurements of real targets (vessels, airplanes) with those of simple objects, whose re-radiation is calculated theoretically:

5° Final Considerations

The interesting opportunities dealt with in the present work essentially depend on the validity of the observations I have done about the intensity of the backscattered field from vessels and airplanes, and the ability to technically achieve, with the described procedure, a very high receiving sensitivity. As far as the principle of frequency modulation is concerned, it seems to me that there can be no doubt. Nor does it seem to me that the R. Marina and the R. Aeronautica [Italian Air Force] have never performed experiments and systematic measurements on backscattering. Therefore some research should begin by measuring the “re-radiation factors” of different types of vessels and airplanes, that I believe can be comfortably done with an experimental setup such as I have described before. So, I propose the following program:

1° Construction, by private industry, of the various components of the system (entrusting them to different firms for the protection of the secret). Mounting of them and tuning at the E. C. Institute of the Regia Marina in Livorno, to which I could be temporarily transferred.
2° Installation of the equipment on a coastal building, in a location next to areas in which many ships will pass, and a few destroyer boats and a few aircraft can also be available. Performing systematic measurements of re-radiation factors, deducing their real value by comparison with some simple re-radiating elements, whose characteristics can be calculated theoretically.
3° In the case that the said factors would prove to be able to allow the achievement of useful results, go to the study of a ship-borne system for the naval and anti-aircraft shooting, leaving it to other researchers to study the apparatuses for the anti-aircraft defense on the ground, for the search of the vessels by airplanes, etc.

I omit a report in detail about the issues related to anti-aircraft firing (**2**) both to avoid lengthening it, and because it seems to me to have said enough to explain to the Bosses the interest of new research about the problem of re-radiation.

Please bear in mind the desire by S. E. De Feo to see carefully examined reports which will be communicated with promptness to R. Marina as the present state of the work.

I wish to thank General Sacco for the useful criticisms made to my earlier report, and for his comment about the opportunity to prefer a mechanical way for the modulation.

27-4-936 XIV
Engineering Specialist
Head of the 1st Section
Ugo Tiberio

(**2**) In the field of anti-aircraft search, there are two very interesting possibilities: the measure of the height simultaneous with that of the distance, and the measurement of the speed of the target. In fact, the backscattered waves reach the receiver either directly or indirectly after being reflected from the ground: the difference between these two paths must give rise to interference effect with highs and lows of sound that allow us to measure it and to derive the height of the aircraft by means of geometrical relationships. To infer the value of the speed, it should be borne in mind that the tone perceived at the receiver side is the sum of that which would occur if the aircraft were immobile and that due to its speed, which has a frequency equal to twice the number of wavelengths that the aircraft travels in one second: since the latter value does not depend on the speed of the motor, it suffices to make two

measurements with different speeds of the latter to obtain the speed of the airplane. Englund, Crawford and Mumford (Proc. I. R. E. 933 Vol. 1 p. 475) have already noted that an airplane passing along a link to ultra-short waves gives rise to beats.

At the point 5°—final considerations—a part is of particular historical interest: Ugo Tiberio, since 1931 engineer at the *Instituto Militare Superiore delle Transmissioni* in Rome, requests his transfer to R.I.E.C. in Livorno (the current Mariteleradar), which took place in the same year 1936.

The "Found Manuscript" does not end with the date and the signature by Tiberio: in an interesting Appendix, reported in [SMM 98], Tiberio analyzes the measurements by Trevor and Carter of the propagation of a 5 m wave above the sea, published in March 1933 in the IRE Proceedings (Vol. 21, No. 3) and the reflections of waves by metal plates studied by W. Seiler (*Zeitsehr für Hochfreq.*, Vol. 37, March 1931, p. 79). The aim is to estimate reasonable values of the backscatter characteristics of targets such as ships and airplanes.[3]

Finally, attention should be paid to note (**2**) above. It contains two totally new concepts in Italy at that time: the measurement of the height of an aircraft and the measurement of its speed by the Doppler frequency, decoupling from the latter frequency the contribution of the distance.[3]

Summing up, in the manuscript by Tiberio most of the basic concepts and main technical solutions for the future radar are anticipated, including:

- the measurement of the distance in frequency modulated continuous wave (FMCW) systems by beating the reflected wave with the generated one;
- the superheterodyne receiver with a single reference oscillator, with the intermediate frequency being obtained by frequency multiplications and sums;
- the measurement of the radial velocity of the target via the Doppler frequency;
- the measurement of the height of an aircraft using the reflection on the sea surface[4] and, of even more recent interest,
- the use of two time delay measurements (via beats, in the FMCW mode) from two antennas located in different positions in order to obtain the azimuth angle of the target (a sort of *ante litteram* interferometer).

[3]Tiberio paid much attention to the very fundamental concept of reflectivity of radar targets, today expressed in terms of "radar cross section". He applied this concept to complex targets by decomposing them into elementary reflectors such as plates and wires. He emphasized the importance of the measurements of the backscattered field and of the calibration of the measurement setup with simple reflectors with known characteristics.

[4]This method is applied in modern radar systems for airborne surveillance such as the E2-C (Hawkeye).


Fig. 2.2 General Luigi Sacco



From the mention of the "Preliminary Report" read by General Sacco,[5] a remarkable person, "instigator" of the Italian radar (Fig. 2.2), it is clear that, likely at the end of 1935, Tiberio presented his "first" report in which the problem of radio-metering and localization was theoretically developed and resolved, with calculations and an examination of the experiences abroad. That report, which of course was secret, shows, for the first time, the fundamental equation, which permits computation of the radar range. Unfortunately all traces of this document were lost, together with all the monographs of the *Gufo*, due to the war events.

In fact, because of the bombings, the RIEC was decentralized (together with the laboratory in the site Le Selci-Firenze for the development of the power tubes wherein prof. Nello Carrara[4] worked) in the—less exposed—Campo San Martino, in the town named Piazzola sul Brenta (Padova). In [Tib 79], Ugo Tiberio recalls that the numerous technical documents related to the *Gufo* were destroyed on September 9th, 1943, in Campo S. Martino. After the armistice of September 8th, 1943 the group of researchers was dispersed; the Naval Academy—and with it Tiberio, Carrara, Lombardini and others—, was transferred to Brindisi where, anyway, they created a small laboratory for teaching and research, which was equipped by using some radar equipment and electronic interception receivers recovered aboard an airplane abandoned at the nearby air force base. Professor Tiberio regretted more than once the loss of the documentation produced at the RIEC until September 8th, 1943, showing results ahead other researchers in the

[5]Luigi Sacco (August 1st, 1883—December 5th, 1970), is the author of the celebrated "Manual of Cryptography" and is considered to be the "inspirator" of the Italian radar; at the time, he was chief of Transmissions in the "Direzione Superiore Studi ed Esperienze" of the military Engineering. In 1926, in order to characterize the antenna radiation at great distances, Sacco introduced the concept of *Cimomotrice* force, then used by Tiberio and Barzilai.

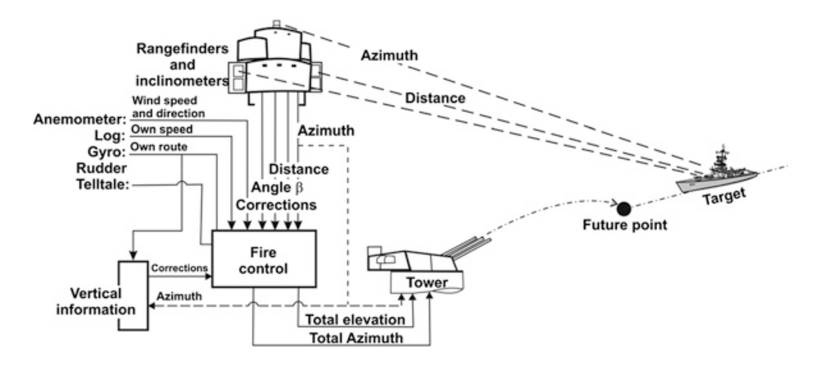


Fig. 2.3 Fire control system and naval telemetry

world. Fortunately, as already shown, in 1996 the members of the Ugo Tiberio family found a hand-written copy of this “second” report dated April 27th, 1936–XIV, a few months after the “first” destroyed report written in 1935. The “Found Manuscript” is currently saved at the Naval Academy in Livorno, after the solemn ceremony in which the son Paolo Tiberio delivered it to the Chief of Staff of the Navy, Admiral Guarnieri, in February, 2000. The very few R.I.E.C. documents, classified “secret”, that were not destroyed, including the “Found Manuscript” by Tiberio, made long laps: from Livorno they were transferred to Campo S. Martino (Padova) where the Naval Academy was transferred, and then to Brindisi, then back to Livorno.

The manuscript, as shown, is very interesting both under the technical-scientific point of view and under that of operations, i.e. the use of radar. The application part is summarized in the table of contents of the manuscript, where the following aims are listed:

1. to detect the presence of a ship, invisible due to darkness or fog,
2. to measure its distance,
3. to determine its direction.

Obviously the problem of naval combat was quite clear to Tiberio: in low visibility conditions it was impossible to correctly perform the classical procedures of (a) to detect an enemy ship, (b) to determine its direction and distance with optical means (naval rangefinder) (c) to calculate the aiming of the guns, (d) to adjust (tune) the shooting (gun laying), lengthening if the columns of water resulting from the projectiles were in front of the enemy ship, shortening in the opposite case. The rangefinders (see Fig. 2.3) by their own nature had an increasing error at increasing distances, just where accuracy was essential.

Tiberio concludes that these three aims can be achieved, and that the method can be used even for the following purposes:

4. to improve, in visibility conditions, the indications of the optical range finders of the Navy;
5. to detect enemy aircraft;

6. to measure, on board an airplane, its height from the ground;
7. to detect a ship from an airplane for the purpose of torpedoing.

In an almost prophetic way, Tiberio anticipates the air defense radar (item 5°), the radar altimeters (or radio-altimeters) (item 6°), and finally the airborne radar for actions (e.g.: torpedoing) against naval targets, those that will soon be called ASV: *Air to Surface Vessel*. Summing up, in these sentences by Tiberio all the radar developments in the convulsed period of the Second World War are outlined, with the only exception of radar imaging to aid night bombing: in fact, in 1936 it was inconceivable, also to Tiberio, that in a few years the resolution of radar could improve so dramatically. A similar awareness of the operational requirements for radar, for example, is totally absent in what Guglielmo Marconi has written, or said, during those years, as already shown.

Before proceeding with the adventure of the *Gufo*, it can be interesting, especially to readers having no special knowledge in radar, to remark some of the technical and scientific concepts present in the manuscript.

The first, fundamental, point in radar is the choice of an operating frequency. Tiberio has clear in his mind two fundamental aspects (a) the maximum power that can be generated in the microwave region was much less than in the metric wave, at that time called "ultra-short wave" region; in general, the power decreases (even today) as the frequency increases; (b) the directivity of an antenna[6] (at the time of Tiberio the term "aerial" was used) depends on the ratio between its characteristic dimension (e.g., its diameter) and the wavelength. Tiberio, probably aware of French experiences on wavelengths below 30 cm, uses the word "microwave", proposed for the first time by Nello Carrara (Carrara's works and French experiences will be discussed later).

The range of frequencies that can be used for radio communications and radar is depicted in Fig. 2.4.

The second element of Tiberio's Manuscript is the substantial difference between radar transmission and reception in a continuous wave mode and in a pulse mode. In the former, directly derived from the radio communications, a beat of the transmitted oscillation with the received one (i.e., the target echo) is created. The difference of their frequencies is due to the Doppler effect, with values often in the audible range, then, detectable by the operator with a headset. However, if the target has zero radial velocity (because of being stationary or transversely moving with respect to the radar), there is no audible tone, but Tiberio teaches (see above) to "take advantage of the time that the reflected wave employs in the return path in order to change the frequency of the transmitter". That is, to modulate the transmitted frequency, in particular with the simple "saw-tooth" law (shown in

[6]When the wavelength is of the same order as the size of the antenna, an antenna is "poorly directive" with radiation, roughly speaking, in "all directions"; vice versa for wavelengths somewhat smaller than this size, an antenna can be designed so that it radiates in a "narrow" angular sector, which is also called the "main lobe" or simply the "antenna beam".

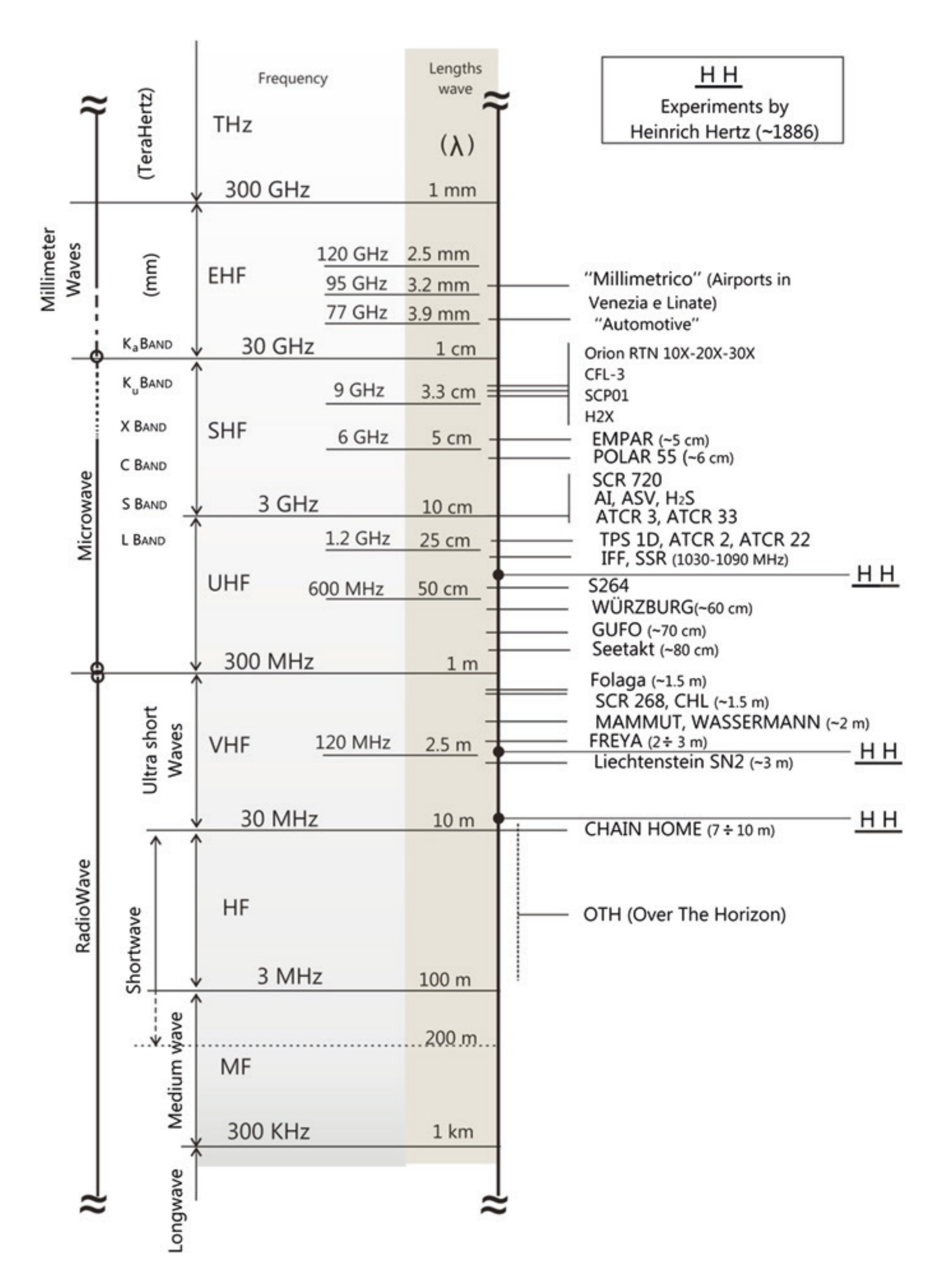


Fig. 2.4 The range of radio and radar frequencies and the placement of some radar equipment

Fig. 1, drawn by hand, of the original Found Manuscript and substantially equal to the one shown in Fig. 2.5). Today we speak of FMCW signals, such that the frequency deviation of the beat is proportional to the distance R of the target, as shown in Fig. 2.5.

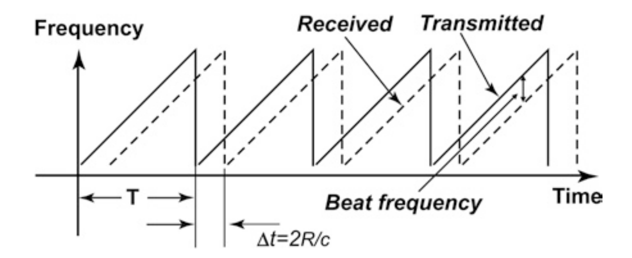


Fig. 2.5 Distance measurement in an FMCW radar (T: waveform repetition period, *R* distance, range)

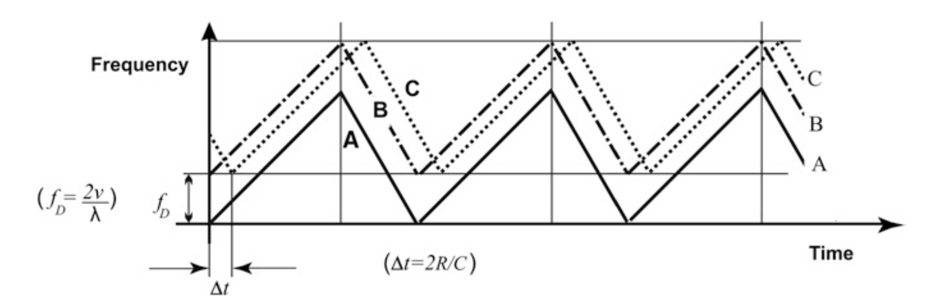


Fig. 2.6 Double-slope "saw-tooth" frequency modulation to measure the distance and the radial velocity. (*A* transmitted signal, *C* received signal from a target at distance *R* and radial velocity *v*, *B* as C, with R going to zero)

When the radial velocity is not negligible, following the ideas proposed by Tiberio in his Manuscript, it is necessary to change the modulation frequency; see, for example, Fig. 2.6: from two values of the beat frequency it is possible to obtain both the delay Δt (and then, the distance R) and the Doppler frequency f_D (and then, the radial velocity).

As Tiberio explains, using the FMCW system the sensitivity increases due to the video integration during the modulation period[7]: thanks to the gain in signal to noise ratio it is possible to transmit with a relatively low power. On the other hand, with this system, the measurements are more difficult with multiple targets and unwanted echoes such as those of the waves of the sea. In fact, today the majority of the surveillance radar uses the pulsed technique, as described in Fig. 2.7, by accepting the disadvantage, as compared with the FMCW, of a much greater peak power with the same range performance.[5] The continuous wave radar is

[7]The beat, followed by a video amplifier which acts as a low-pass filter, is equivalent to a correlation receiver, implementing a matched filter, [Tur 60].

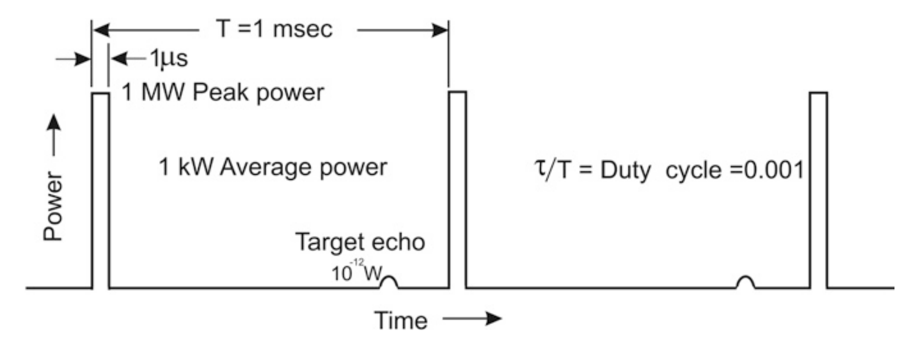


Fig. 2.7 Typical waveform for a pulse surveillance radar with a pulse duration of 1 μs and a pulse repetition period of 1 ms

appreciated today, in military applications, for its low peak power that makes it more difficult to be intercepted by the enemy (LPI, Low Probability of Intercept, characteristic).

In this regard, it should be remembered that Tiberio, who in the Found Manuscript presents the FMCW system as the only solution, with his research and experimentation going on, becomes convinced very soon that, at least for the naval applications that interest him, the most suitable solution will be the pulse radar; however, he must obey his superiors, in particular Giancarlo Vallauri,[6] a proposer of the continuous wave technique, considered “simpler and cheaper”. In his memories, Tiberio speaks of the period dedicated to a continuous wave radar as a waste of time.

The choice between pulses and continuous wave is present in the whole radar history. The continuous wave (CW) solution was preferred in some periods and neglected in others. For example, at the end of the 1990s, it was neglected at least by one of the most well-known researchers and authors, Merrill Ivan Skolnik, who in [Sko 01], third edition of his well known book, reduced the chapter on CW radar, present in the previous editions, to only four pages (pp. 193–197), in which he substantially maintains the superiority of “Pulse Doppler” radar on the CW one, and lists in detail the limitations of the latter. On the other hand CW radar has resumed its position, especially for applications at medium and short range, in this century.[7]

The birth of radar from radiotelegraphy made it initially “Bistatic”; this term (due to someone who obviously was not deeply familiar with the ancient Greek, otherwise he would have preferred the term “distatic”) indicates the physical separation between the receiving antenna and the transmitting one, which is natural in CW applications. The *Gufo* (with its predecessors) was and remained Bistatic (it had two identical antennas, rotating together), like many of the radars used at the beginning of the Second World War. On the contrary, a “Monostatic” radar uses one antenna in “time-division”, which is natural in pulse systems, having a small portion of the time (often, in the order of a thousandth) dedicated to transmit, and

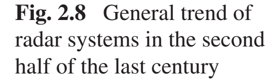


Fig. 2.8 General trend of radar systems in the second half of the last century

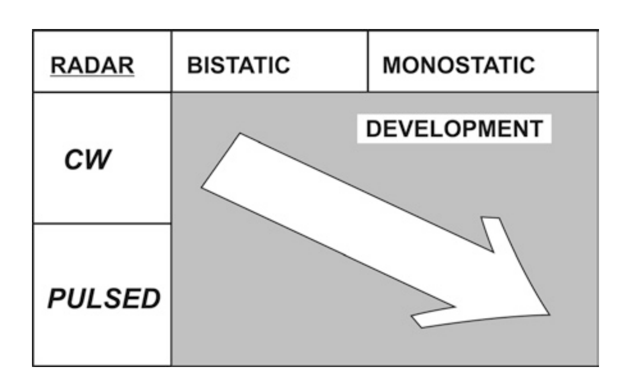
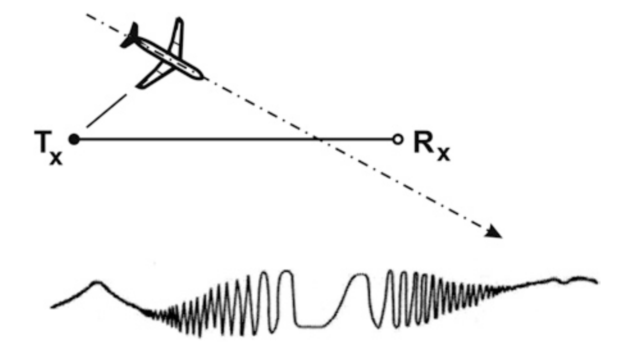


Fig. 2.9 The "beat" phenomenon when an air target crosses a radio bridge. Note that when the target is on the line joining the Tx (transmitter) antenna with the Rx (receiver) one, the Doppler frequency goes to zero



the remainder to receive, Fig. 2.7. As a conclusion, from the end of the war, the evolution has followed the direction of the arrow in Fig. 2.8, but not without the "backfires" in cycles of 20 or 25 years, well highlighted in Chap. 2 of [Wil 07].

Finally, as shown before, Tiberio was aware of the experiments that did occur in the USA in 1932 and were reported in the scientific literature in 1933 in which an airplane, passing along a link to ultra-short waves, gives rise to beats. This is (see Fig. 2.9) the phenomenon today called *Forward Scattering*, in which the scattered field from a moving target, the frequency of which is modified by the Doppler effect, adds constructively or destructively with the radiated field, generating in reception of the "beats". For targets as fast as aircraft, the frequency of beats is often in the audible range: as discussed in the previous chapter, Marconi himself (without showing to have read the work of Englund, Crawford and Mumford (1933)), observed, like many others,[8] the phenomenon.

The beating method was applied in France from its main inventor, Pierre David, who organized tests on June 1934 in Le Bourget, and subsequent ones in November. In about a year, he gathered more than 500 recordings of "beats" due to

[8]On pages 15 and 16 of [Wil 07] there is a list of experiments (1922–1933) in which the presence of moving objects (but not their exact position) was detected due to their crossing of a radio link.

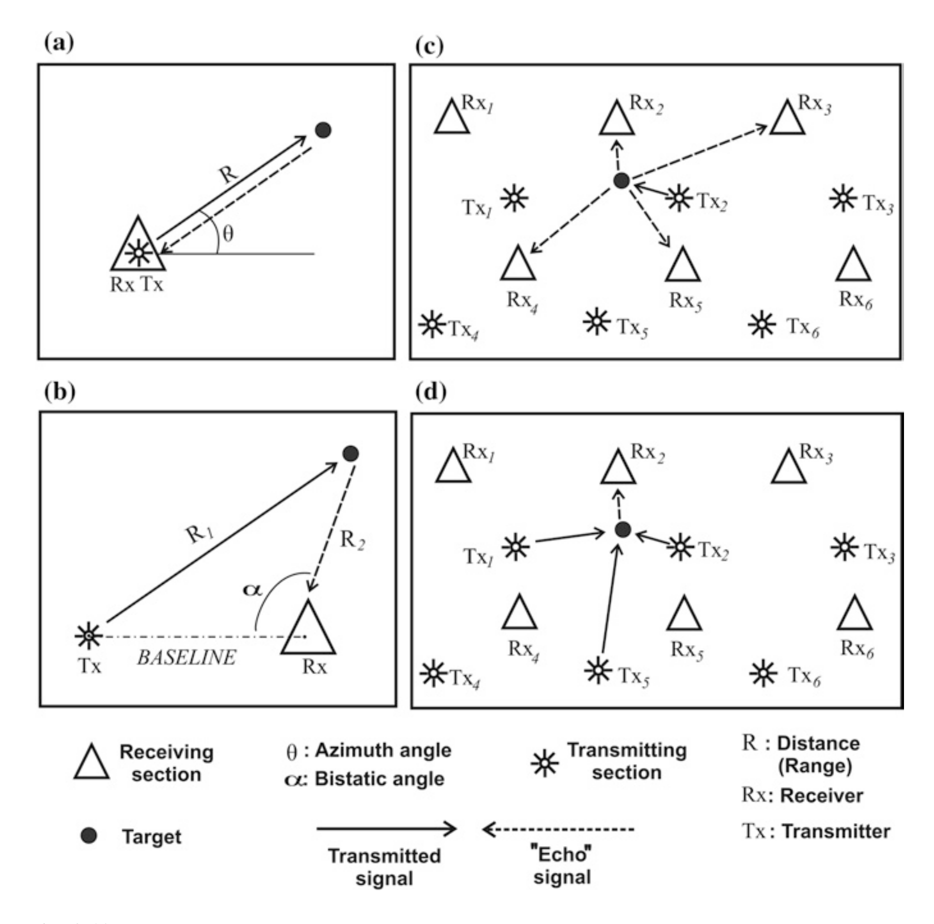


Fig. 2.10 Configurations: **a** monostatic, **b** bistatic, **c** multistatic with transmission from Tx_2, **d** multistatic with reception from Rx_2

the passage of aircraft in “electromagnetic barriers” and tried to relate their parameters with the direction and speed of the aircraft. As is evident, the “experiments” by Marconi in May 1935 (Chap. 1) are a very poor thing in comparison. David organized a network of barriers called “*maille en Z*”, i.e. in the form of a Z, in which he tried to overcome the problem of the lack of information of the distance by exploiting more detections of the same aircraft. In fact the time instant of crossing the line that connects a transmitter and a receiver was known, but not the crossing point. By combining more measures for aircraft in uniform rectilinear motion, in was possible to determine the velocity with errors of about 30 % and the direction with errors of about 20°. This system was made operational in 1939; the French navy planned the coverage of the coastal area of Britain around Brest, the main French military base, and around the ports of Cherburg, Toulon and Bizerta (Tunisia) [Roh 05]. This system can be considered as a forerunner of the modern *multistatic* systems, in which multiple transmitters and multiple receivers cooperate.

The concept of monostatic, bistatic and multistatic radar is shown schematically in Fig. 2.10; it can be seen that in the monostatic case, the measurement of the position of the target on the horizontal plane (plane of the drawing) requires at least two measurements, the distance R (the so-called Range), and the angle θ (the so-called Azimuth) with respect to a predetermined direction, typically the North; in the bistatic case, the circle centered on the radar with radius R becomes an ellipse with foci the transmitter and the receiver, calling for other information: the bistatic angle α, or (going toward the multistatic system) a second measurement from another pair of points. In the multistatic case, the position may be obtained from measures of delay (and possibly of Doppler frequency), without the need for angle measurements.

Figure 2.10 shows a multistatic situation in which the transmission is only from Tx_2 and the reception is in the four stations closest to the target: with three receiving stations, three ellipsoids are generated as constant-delay curves, the intersection of which determines, in principle, the position of the target. If the other stations, e.g. Tx_1 and Tx_5, transmit, simultaneously with Tx_2, orthogonal signals, a much greater wealth of information can be obtained for a better identification and localization of the target with a lower risk of ambiguity. This topic will be also treated in Chap. 10.

2.3 Birth of Radar in Italy

Let's go back to 1936 in Italy, where the working group led by Ugo Tiberio at the *Regio Istituto Elettrotecnico e delle Comunicazioni* (R.I.E.C.) of the Navy, in Livorno,[9] was entrusted with the task of going from theoretical studies to the experimental phase of radar development. Tiberio, in the meantime, was appointed officer in the body of the Naval Weapons and transferred to the Academy as a professor of physics and of radio-techniques. The financial resources and the staff available to the development of radar were, however, limited (four petty officers, some workers and an annual allocation of 20,000 lire—about 13,000 Euro), for which Tiberio had to carry on, almost alone, the development and implementation of a prototype of the *Radiotelemetro*. Soon Nello Carrara, another professor of physics at the Naval Academy, joined Tiberio. By 1924 Carrara, a young physicist, was working at the R.I.E.C. and, since 1932, did research in the field of microwave; he was mainly responsible for the design and implementation of power tubes,[8] basic components in order to obtain acceptable values for the radar range. Carrara and Tiberio never interrupted their commitments to teach (lectures, tutorials, training handouts, committees of examination). In 1937 another notable person joined the group of researchers: the captain of the Naval Weapons Alfeo

[9]The Institute, which was commonly called "E.C." or Mariteleradar, or, from the telegraphic initials, "Marinelettro", is dedicated to Prof. Admiral Giancarlo Vallauri who was its first director.

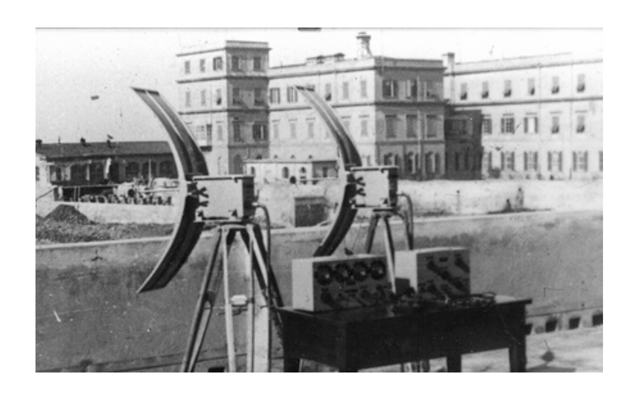


Fig. 2.11 E.C.-1 Radar in test on a terrace of the R.I.E.C., 1936

Brandimarte[9] who immediately began to work on construction of the new prototype of the E.C. 3, a pulse radar, which will be described soon. This collaboration, however, was short lived because the possibility of career progression in the Italian Navy was precluded to Brandimarte (who in 1944 fell as an opponent in the "Resistenza") for the strange and inappropriate fascist law "on celibacy"; therefore, the research team again consisted substantially in the tandem Tiberio-Carrara.

With scarce resources, Tiberio implemented several experimental sets, starting from (in 1936 and in a few months) the first experimental Radio Detector Telemetro (the name used in Italy at that time, abbreviated as RDT). This frequency-modulated continuous wave radar, designated with the initials E.C. 1 (*Elettronica e Comunicazioni* 1, to indicate the R.I.E.C.), dedicated to the practical demonstration of the RDT concept and to the measurements of radar cross section.[10] It worked at 200 MHz (i.e. at the wavelength of one meter and a half)[10] in the just described FM-CW mode (the reasons for the choice of the continuous wave solution was explained before), had a pair of reflector antennas with a parabolic cylindrical section and was used for the practical demonstration of the theory of the radar equation. On that occasion, an experience was set up with the apparatus being installed on a terrace of the Institute (Fig. 2.11) with the use of a boat as a target of opportunity (Fig. 2.12).

The first results, although not fully satisfactory, served as an experimental verification of the calculation of the maximum range (radar equation). The maximum distance at which it was possible to receive useful radar echoes, of the order of 2000 m, in fact, was too little for tactical naval applications. This apparatus was also used in experiments to identify a friendly unit at night, in practice as an IFF: *Identification Friend or Foe* for naval units, see Figs. 2.12 and 2.13. In this

[10]We will use either the *wavelength* λ (preferred at the time of Tiberio) or the *frequency* f (preferred today in the West, while in the former-Soviet Union the wavelength is more often used); it is well known that their product is the speed of light, about 300 m/μs, hence the practical conversion rule:

$$\lambda(\mathrm{m}) \cdot f(\mathrm{MHz}) = 300.$$

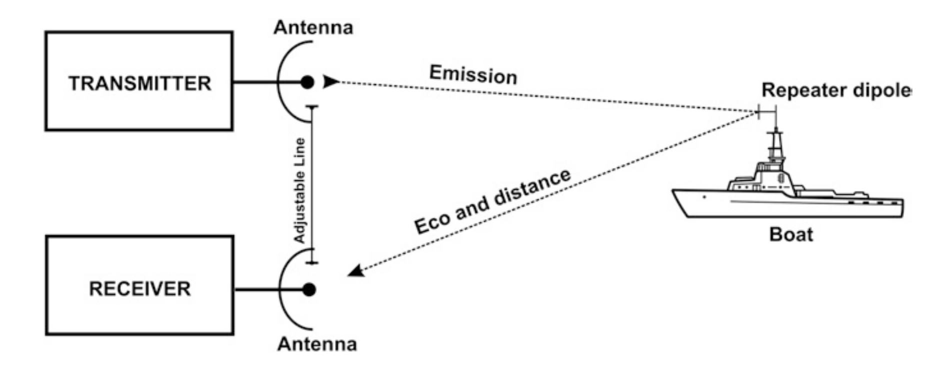


Fig. 2.12 Radio detector telemeter (RDT) E.C. type used for *identification friend or foe* (IFF), 1938

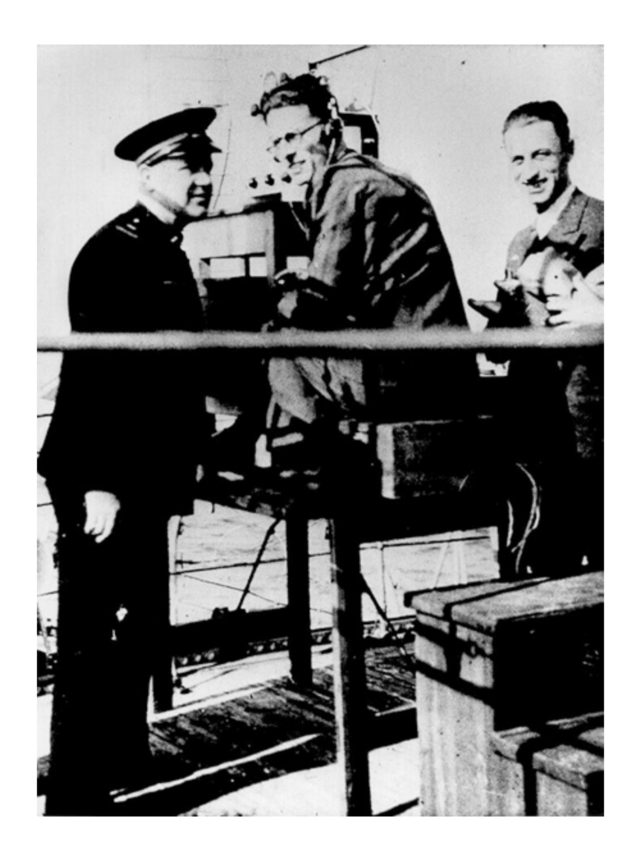


Fig. 2.13 Radar trials for ship detection (1937), from *left* A. Brandimarte and N. Carrara

application, the radar operated at a fixed frequency and received the modulated echo produced by a rotating dipole on the unit to be recognized as friend.

In this first embodiment of a radar prototype in Italy, the problem of the transmitted power arose immediately. In fact, while in radio broadcasting and radio-telegraphy

the received signal—assuming a free space propagation—is spread over a spherical surface centered on the source and then fades in proportion to the square of the distance, the radar signal has the outward and the return path, and the power of the echo fades with the fourth power of the distance, as shown in [Tib 39], the first published version of the "fundamental radar equation".[11] As many others, the paper [Tib 39] published on *Alta Frequenza* in May 1939 was summarized in "The Wireless Engineer", August 1939, in a brief note (no. 3175). The limited availability, in Italy, of technologies suited to the required high power levels (from hundreds of W to some kW) in the frequency ranges of interest was one of the main limitations to the development of operationally efficient radars; once the RIEC made the choice of the pulse solution, the problem was exacerbated by the fact that the technique of vacuum tubes in those times, especially of their cathodes, was developed for the continuous wave radio: it was unsuitable to the high peak power, pulsed operation.

The ensuing version of the RDT, named E.C.1-bis, (1937) differed from the previous one by the use of a superheterodyne receiver (for the remaining aspects, it was very similar to the E.C.1), but did not gave satisfactory results for complications in the development of the heterodyne device[12]; therefore it was promptly abandoned.

Very different was the ensuing prototype (in the same year, 1937) named E.C.2. It was based on the pulsed technique and used RCA triodes model T 800 (i.e. produced in the USA, a nation that would become an enemy in short time), operated on the 1.7 m wavelength, slightly higher than the E.C.1, had a equal-phase dipoles antenna and an oscilloscope-type display. Unfortunately, the results were unsatisfactory for a combination of practical disadvantages (some strong shocks within the transmitting tubes prevented the smooth operation of the system). In 1938, the Naval Weapons Directorate of the Navy, eager to reach in a short time to a working prototype, signed a contract[13] with the company SAFAR.[11] It has been reported that this agreement did not lead to successful results[14] because of the different views between SAFAR and Marinelettro, and more specifically, according to somebody, between Ugo Tiberio and the technical director of the company, Dr. Ing. Castellani[12] (he was a remarkable engineer, inventor and designer of radio equipment and radar).

[11]In the formulation by Tiberio, who uses field strength in place of power density, the square of the distance appears in place of the fourth power.

[12]A complex mechanical device modulated the heterodyne frequency with constant offset with respect to the transmitted frequency. The heterodyne receiver is due to Lucien Levy in 1917, and patented by Armstrong in the following year.

[13]A clarification is needed, as in [Tib 79] and in [Cer 95] a noticeable aspect is clearly indicated: the contract was signed with the clause "without fixed expenditure limits", a remark entirely absent in the always well documented works by Castioni such as [Cas 87], presumably because that clause contrasts the claim by Castioni that the Italian Navy was severely limited to expenses for the radar development, at least until the Capo Matapan defeat.

[14]See [Cas 87] where, however, for a likely clerical error, the contract Marinelettro-SAFAR in 1938 is referred to the E.C.3 instead of the E.C.2.

The discussion between Marinelettro and SAFAR basically ended with the request by SAFAR—obviously, not accepted—of secondment of R.I.E.C.[15] staff to that firm. The always balanced and elegant Ugo Tiberio, who certainly knew the matter very well, sums up this situation in a single, elegant phrase that deserves to be given in full, from [Tib 79]: "This initiative could not take place due to the difficulty of recruiting the needed technical staff".[13]

However, given the slowness with which the industry implemented what was designed by the researchers and given the small produced quantities, the Navy had to find other ways to obtain the peak power required for an acceptable radar range. With the international market still open, they could initially purchase from the USA, at the RCA, powerful enough vacuum tubes needed to meet the requirements of the researchers. Two prototypes were tested at the R.I.E.C. from 1939: the coastal apparatus called RDT 3 (in some documents: E.C.2-bis), and the naval one called E.C.3, (from December 1940 modified as E.C.3-bis). These trials showed some possibility of achieving significant operational results. However, only with the introduction of the E.C.3 set (a pulse radar, with a double horn antenna, operating on the 70 cm wavelength, developed at the R.I.E.C. from the end of 1939, using conventional Philips triodes in transmission and a new, highly sensitive super-reaction receiver) the possibility of obtaining significant results in truly operational uses was open. The next model E.C.3-bis (1941) had a simpler but less sensitive superheterodyne receiver and a higher transmission power (1 kW) thanks to the new Philips tubes (again of the conventional type, for radio-communications) with a greater cathodic efficiency. Unfortunately, because of the chronic lack of funds (and probably a not complete understanding of the operational value of these new equipments) from 1940 the research and development work had a slowdown both by the need for further tuning, and by the limited interest by the summits of the Italian Navy. As Pietro P. Lombardini, who was the youngest collaborator of Tiberio, recalls, the first detection (by acoustic receiving) of a tug at approximately 2 km offshore from the Academy of Livorno took place on April 14th, 1941.

The hectic restart of Italian radar activities during the wartime period, precisely in April 1941, immediately after the well known Cape Matapan night naval battle, with the involvement of the industry, will be explained later in the following. Summing up, at the date of Cape Matapan two types of prototype were available at R.I.E.C. One of them, designed for coastal installations[16] (Figs. 2.14 and 2.15),

[15]To highlight the difficulties in which this small *team* operated, it seems appropriate to reproduce, verbatim, what Ugo Tiberio wrote in 1951, always with his "understatement" and, notably, without mentioning the name of the firm: "In 1938, due to the difficulty in finding other researchers to devote to his studies on radar, the Ministry of the Navy decided to try to involve an important radio industry in Milan, which, however, having all own staff already engaged, limited itself to ask the needed technicians to the Navy: the Navy could not fulfill this request, so, also this attempt remained without success" (U. Tiberio –*Sullo sviluppo delle cognizioni radar durante la Guerra*—Rivista Marittima—Aprile 1951).

[16]The set was not suitable, because of its large size and physical features, to the naval use.

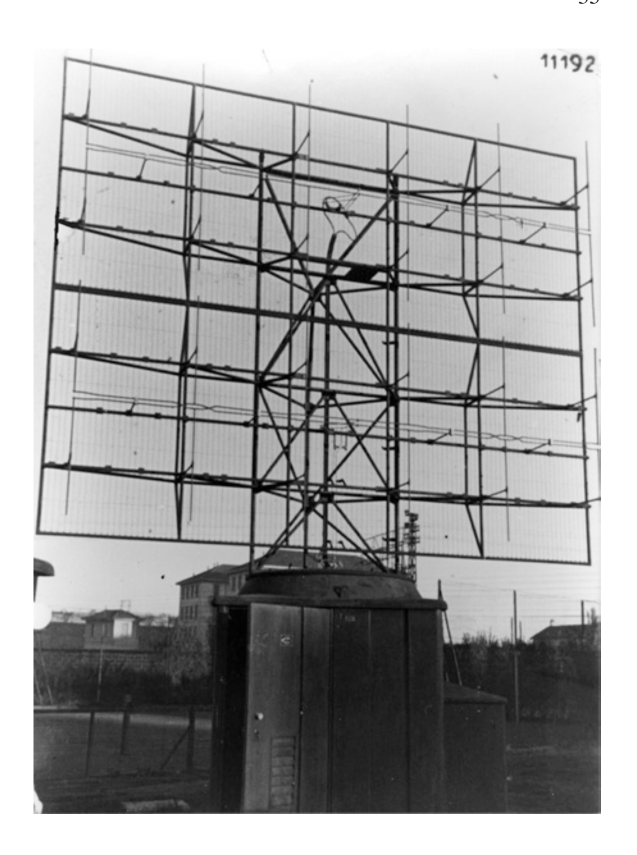


Fig. 2.14 Array antenna of the “Folaga” radar

operated at wavelengths in the range of 1–2 m, nominally 1.5 m, and was called RDT 3 and, later, *Folaga*[17] (or, in the version that, according to some sources, was made by Magneti Marelli, RDT 4/*Folaga*).

The other one, named E.C.3-ter, or *Gufo*, was derived from the E.C.3-bis with the novel FIVRE triodes model 1628, due to Prof. Nello Carrara (Carrara developed the cathodic resonator with high quality factor Q, solving the problem of internal discharges that made, in fact, poorly efficient the previous prototypes). The transmitting modules, implemented in order to be easily replaceable due to their very short average life, were called, because of their shape, the “Carrara’s pots”, see Fig. 2.16. The *Gufo* had interesting performance thanks to its transmitting system having a peak power as high as 10 kW, with which it was possible to detect air targets up to a distance of 120 km and naval targets up to 15–30 km (depending on the installation height of the antennas, typically: 35 m on large battle ships such as *Vittorio Veneto* or *Littorio*, 25 m on cruisers such as *Scipione Africano*, 15 m on destroyers such as *Carabiniere*, *Fuciliere*, *Velite* or *Dardo*).

[17]In English: *Coot*.

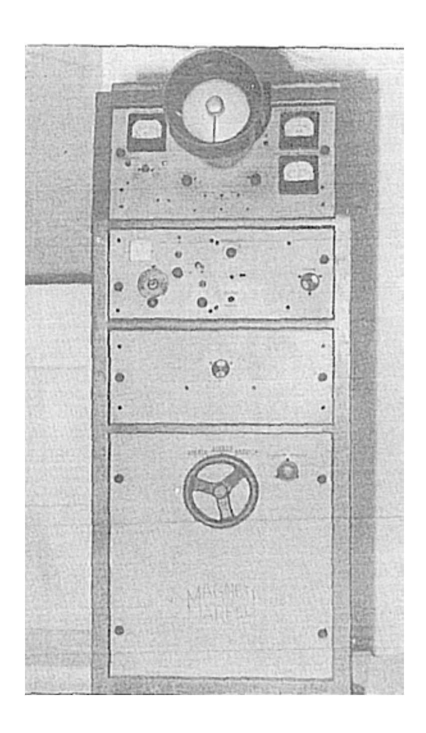


Fig. 2.15 Video detector of "Folaga"



Fig. 2.16 A "Carrara's pot"

Then, the series production of *Gufo* and *Folaga* was entrusted to domestic industry, but this point will be discussed later; however, it is worth mentioning that the reported progress in terms of performance by these last-release sets was truly remarkable.[18]

[18]Because of the secrecy and of the well-known events of the war, most original documents of that time that, today, could be a sure reference (such as detection tests, test reports or similar) are unfortunately lacking. A few significant documents found in the SAFAR/Castioni archives are reprinted in the Appendixes and Complements of [Gal 12].

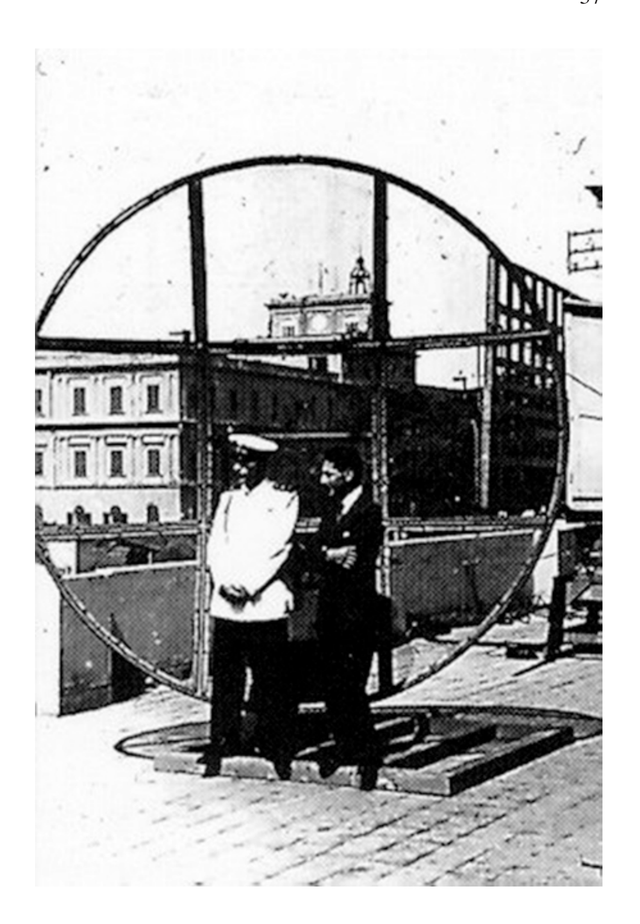


Fig. 2.17 Antenna of the "*Folaga*" radar on the R.I.E.C. terrace (May 1943)

In this respect we recall that with the latest version of the *Folaga* during the experimental tests on May, 1943 (Fig. 2.17), a mass raid of one hundred American aircraft arriving from Sardinia to bomb the city of Livorno was detected at more than 200 km [SMM 98]. In [Cas 74a] p. 30, a range of 300–400 km on air targets is claimed. This is an unrealistic value even with the considerable Folaga's transmitted power of 50 kW; other documents indicate a, probably conservative, radar range of 50 km[19] or, more optimistic, of 113 nautical miles, i.e. 209 km, a value

[19]By applying the radar equation to the estimated technical data of the *Folaga*, it appears that an aircraft target of good reflectivity (radar cross section of 10 m^2) at a distance of 200 km in free space would have generated an echo below the noise (precisely, with a signal-to-noise ratio of—4 decibels), hardly detectable even with assuming a gain of 10 decibels due to the integration of the pulses by the operator. Maybe, being the instrumental range equal to 300 km (due to the p.r.f. of 500 Hz) there has been some confusion with the real, operational radar range.

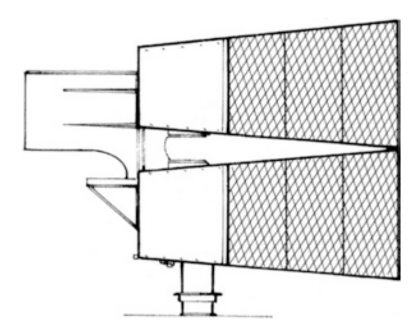


Fig. 2.18 Side view of the E.C.3-ter "Gufo" antenna with the wind-compensating rudder

found at p. 109 of [Cer 95]. In this respect, for the *Gufo*, in [Tib 79] range values on air targets from 80 to 120 km[20] are indicated.

The initial phase (1937–1938) of low activity of Marinelettro on radar can be explained by the lack of qualified human resources: in addition to teaching, since the summer of 1937 Tiberio had to deal with other technical problems (in particular, to the development of radiotelegraphy equipments for the Regia Marina), which presumably were judged by his bosses more important than the RDT.[14] Then, at the beginning of spring, 1937 the lieutenant of *Genio Navale* (Naval Engineering) Ugo Tiberio was flanked (putting him at his orders in spite of being of an higher grade) by the captain (AN) Alfeo Brandimarte, who oversaw the development of the E.C.3 (it seems that this name was used twice) with the new triodes T 800 by RCA, finally able to provide a non-negligible peak power.

A peculiar feature of the *Gufo* (see Figs. 2.18, 2.19, 2.20, 2.21, 2.22, 2.23, 2.24, 2.25 and 2.26)—not found, as it results, in any other radar of that period—was the antenna, or better the pair of antennas of the horn type, with, at a quarter wave length from the bottom, the feeding dipole, usually vertical but that can be rotated by 90°. In [Tib 79] Tiberio explains that this solution permitted the operation in both the vertical polarization, which was normally used, and in the horizontal one. It did not appear possible to install more than just one radar set on each naval unit, and therefore it was necessary that the only apparatus on board could operate in both naval mode and anti-aircraft mode.[21] On the other hand the use of two antennas, a transmitting and a receiving one (Fig. 2.18), was common at that time, as Italy and

[20]On naval targets, the radar range depends on the height of the antenna above the sea level (and on the operational wave length). Range values of at least 20–30 km were necessary, especially in the battle at night or in fog, when using the major naval guns, e.g. the 381 mm (15″), which, with 381/50 mod. 1934, was the main weapon of the battleship *Littorio*, able to hit up to 42 km (36 km when shooting at 30°).

[21]Obviously, Tiberio knew the different propagation behavior of the two polarizations in the presence of the sea surface. However, the horn solution, as compared to the equiphase dipoles one, most used in surveillance radar, had the significant disadvantage of a greater resistance to the wind. In fact, the revolution engine of the antenna of the Gufo, in critical condition for wind or speed of the ship, was unable to perform its function, forcing the radar operators to rotate manually the antenna by means of a hand-wheel.



Fig. 2.19 The light cruiser *Scipione Africano* with the antennas of the RDT E.C.3-ter "Gufo". The position of the antennas allows us to distinguish, at the rear, the rudder added to compensate for the insufficient power of the electric motor in the presence of wind

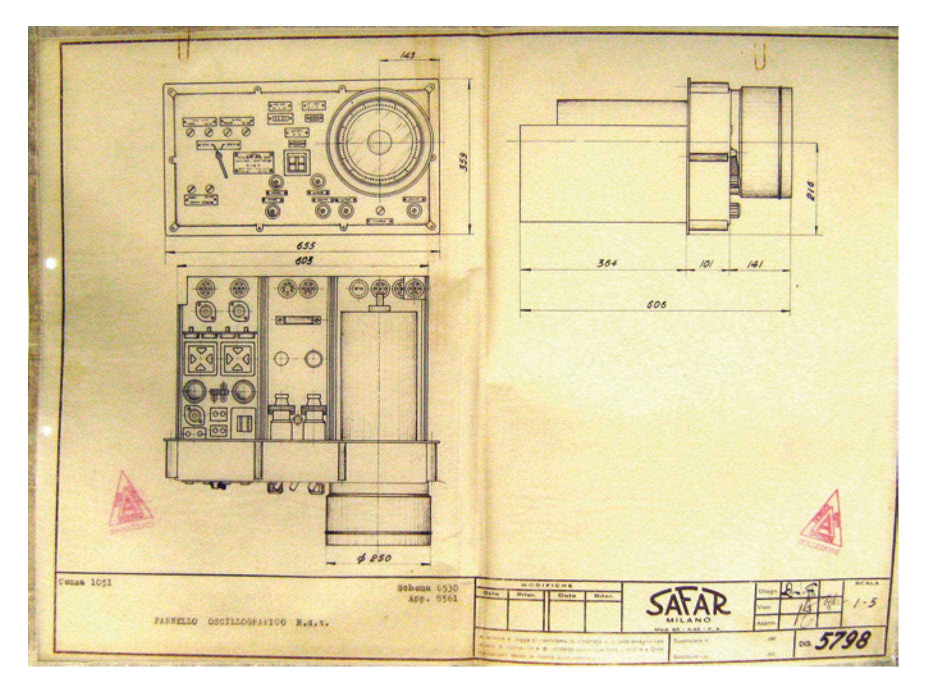


Fig. 2.20 The "Gufo" radar control panel by SAFAR

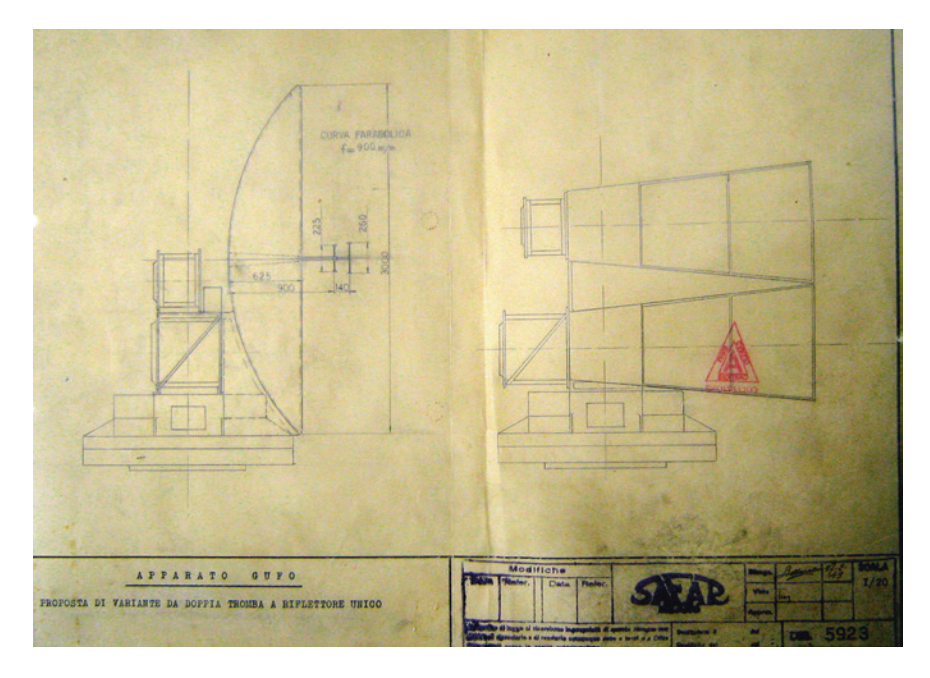


Fig. 2.21 "Gufo" radar—drawing of a reflector antenna to substitute the double horn one

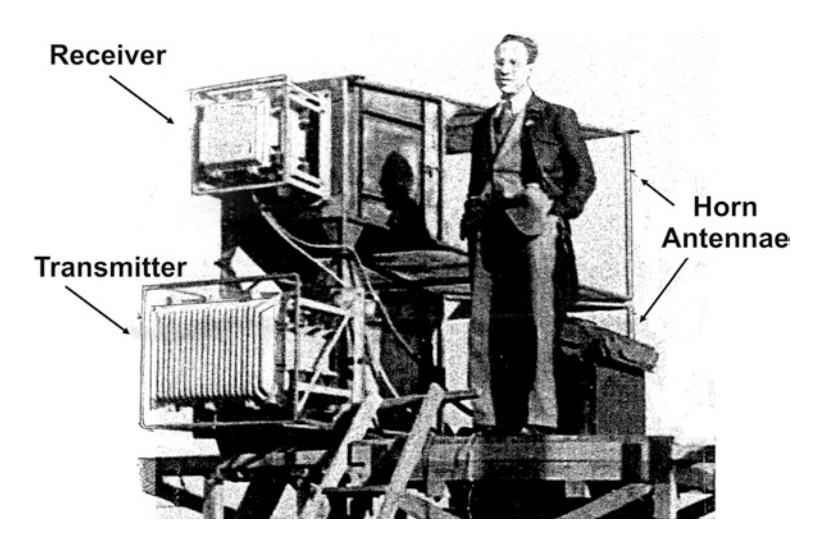


Fig. 2.22 The E.C.3-ter "Gufo" and Federico Brando from SAFAR

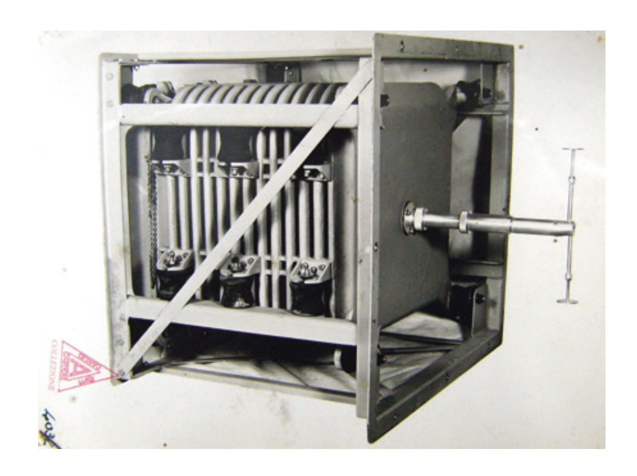


Fig. 2.23 The transmitter of the E.C.3-ter "Gufo"

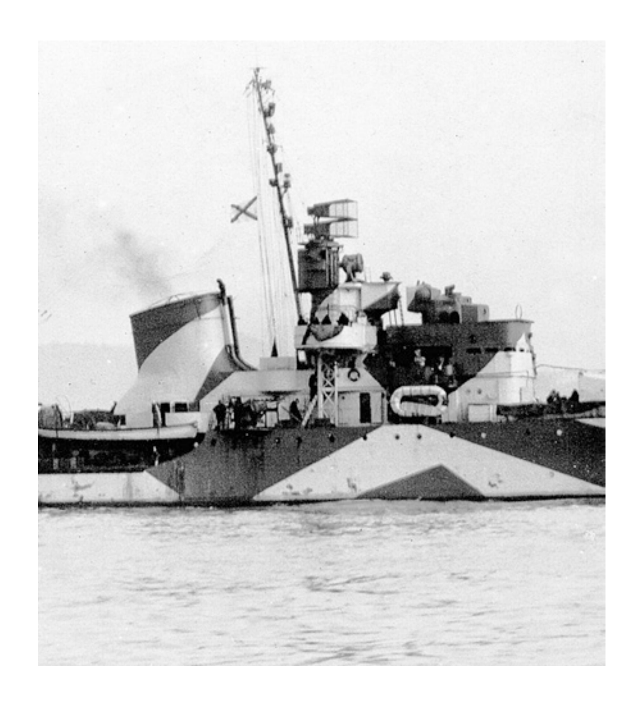


Fig. 2.24 The destroyer *Fuciliere*, equipped with the radar E.C.3-ter "Gufo" from January 1943

other nations lacked the necessary technologies to realize the "duplexer" with which an antenna is connected to the transmitter during emission of the pulse and to the receiver in the remaining time. To solve the problem of the limited gain of this type of antenna, an alternative solution with a parabolic reflector was devised, Fig. 2.21, but it is not known if this was really implemented or, more likely, not.

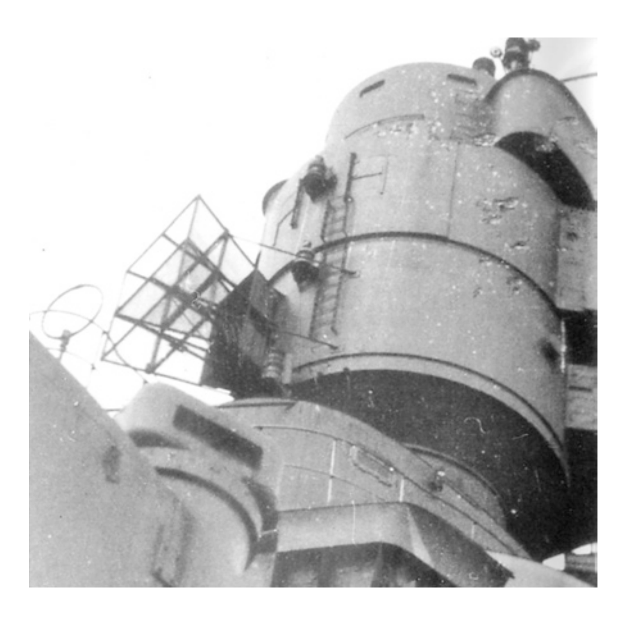


Fig. 2.25 A detail of the tower of the Battleship *Littorio*, end of 1941. The large antennas of the RDT prototype E.C.3-bis embarked for experimental purposes are visible, with the "horns" for transmission and reception

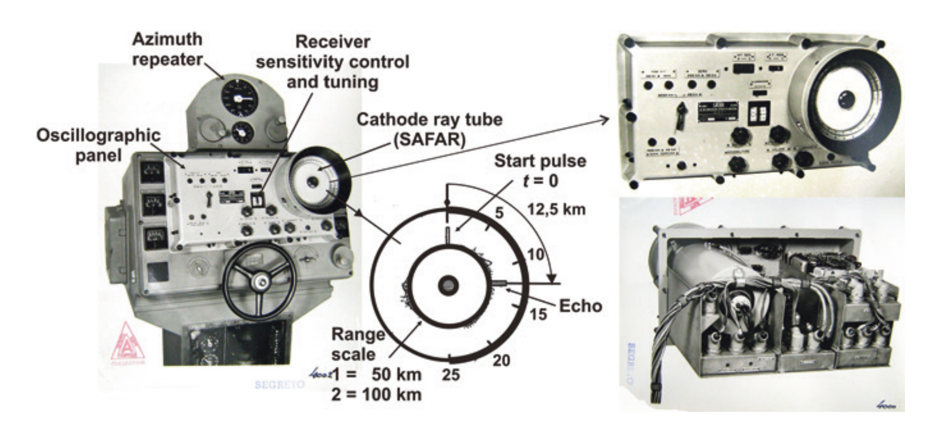


Fig. 2.26 Operating console for the control of radar *Gufo* and G.III, built by Galileo-Firenze (the polar oscilloscope: by SAFAR—Milan); the synchro-repeaters, in the *upper part*, were used to transmit data to the fire control unit

The "Gufo" operator used the console shown in Fig. 2.26, with the hand-wheel (bottom) for the manual rotation of the antenna when necessary. Among the very few block diagrams of the Gufo remaining after the war, in Fig. 2.27 is shown a document which, according to its title and content, clearly is the second drawing

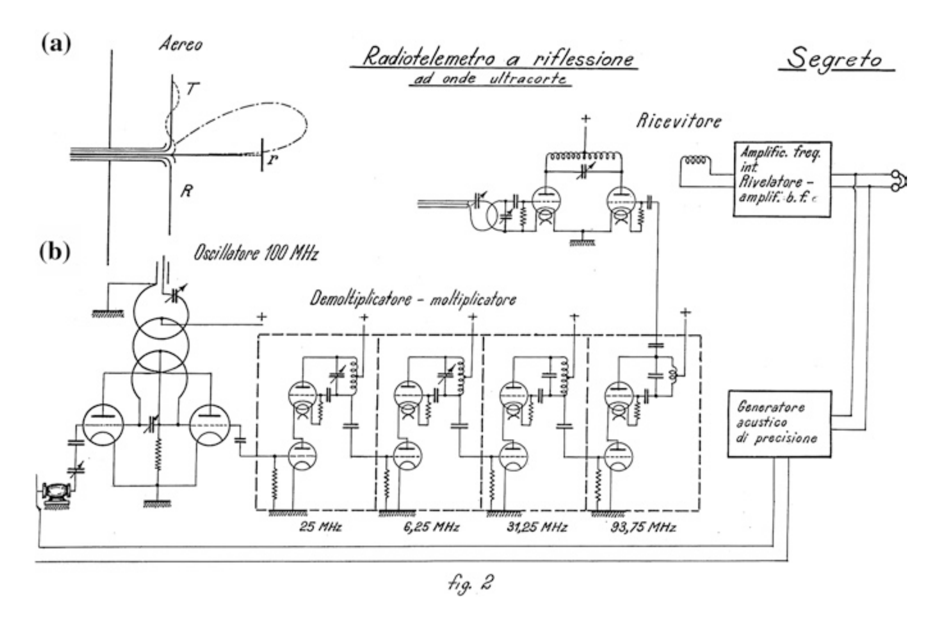


Fig. 2.27 General scheme of the first RDT conceived by Ugo Tiberio, April 27th, 1936

of the "Found Manuscript",[22] quoted in its paragraph 4 ("…in the document here enclosed…").[23]

A diagram of the circuits of the receiver (1941) is shown in Fig. 2.28, highlighting the differences with the scheme of 1936, while the circuit diagram of the transmitter is shown in Fig. 2.29.

After the war, Tiberio continued to deal with radar and radio techniques as professor at the University of Pisa, producing, among other things, the remarkable text books [Tib 51] and [Tib 51b], in which he explained some topics that are still interesting today, such as that of "stealth"[15] targets and of the radar jamming. He had many pupils, some of whom assumed important positions in the nascent national radar industries, which are described in the following. Of course, he was invited by many scientific and industrial institutions for lectures and seminars. During one of these visits, the photograph shown in Fig. 2.30 was taken.

The "RaRi mobilization", with the development of—unfortunately, a few—industrial Italian radars in the early 1940s, will be further discussed in the following; here we present, from pp. 49 to 50 of [Tib 51b], the part where Tiberio very clearly synthesizes the development of radar.

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[22]The first drawing of the "Manuscript" is simply the sketch of the "sawtooth" frequency-modulated signal.

[23]This scheme, which is not physically attached to the "found manuscript", was luckily saved by professor Paolo Tiberio who, on July 2011, has generously provided the A. with the copy presented here, finally allowing a complete reconstruction of this important Manuscript.

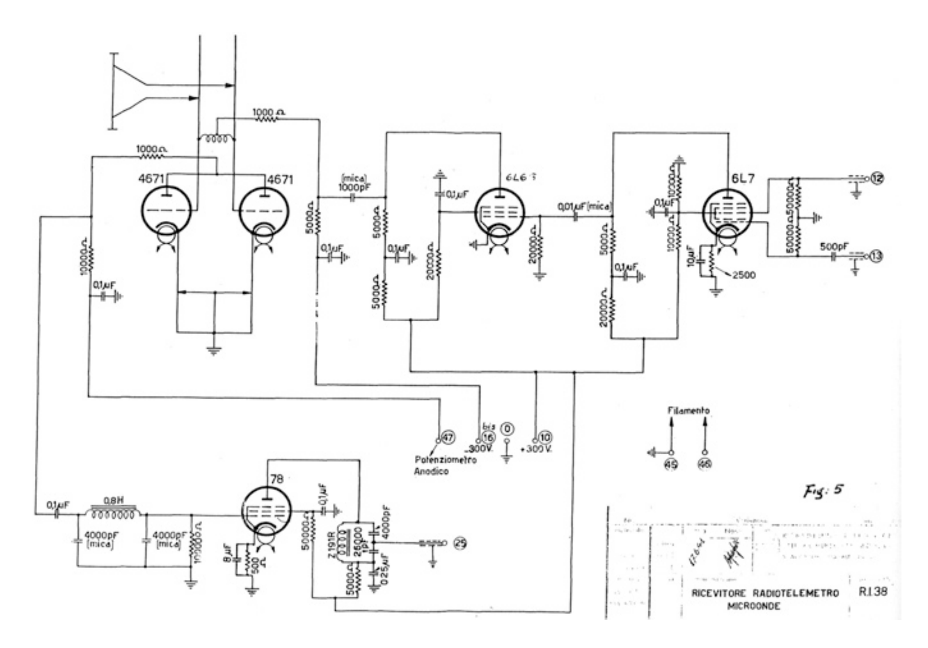


Fig. 2.28 Circuit scheme of the receiver of the E.C.3-bis/ter, June 17th, 1941

"The beginning of the evolution that, from the techniques of ionosphere survey, led to the birth of radar, can be dated in the years '34 and '35, and was determined by two concurrent causes: the development of the of ultra-short wave technique on one hand, and, on the other, the finding of the theoretical possibility to detect the echoes of airplanes up to distances in the range of 100 km. The imminence of the war, however, pushed each of the principal nations to develop—for its own account—secret researches, so that scholars worked at the various countries, in an independent manner up to '40 ÷ '42, after which a first collaboration began inside of each of the two opposite fighting parts. In 1945, the winners proclaimed the end of military secrecy on the general aspects of radar, and began publications of the well-known 28 volumes of the Radar Series.

While addressing the reader calling for a complete knowledge of the history of the former radar research to the specialized publications, we wish to recall that in Italy the initiative was taken by the Navy (Regia Marina), with which, from '34 onwards, the author of this text has carried on research aimed to clarify the theory and to provide equipment suitable to military requirements. A first type of them, operating in continuous wave, was made in '36–'38 with some first, inadequate results; then different types operating in pulse mode were realized in '39 ÷ '40. The first satisfactory results were obtained in '40. In the course of the war, various types of apparatus were constructed and used to an extent which however, for the poverty of the national industry on the one hand, and for the lack of cooperation

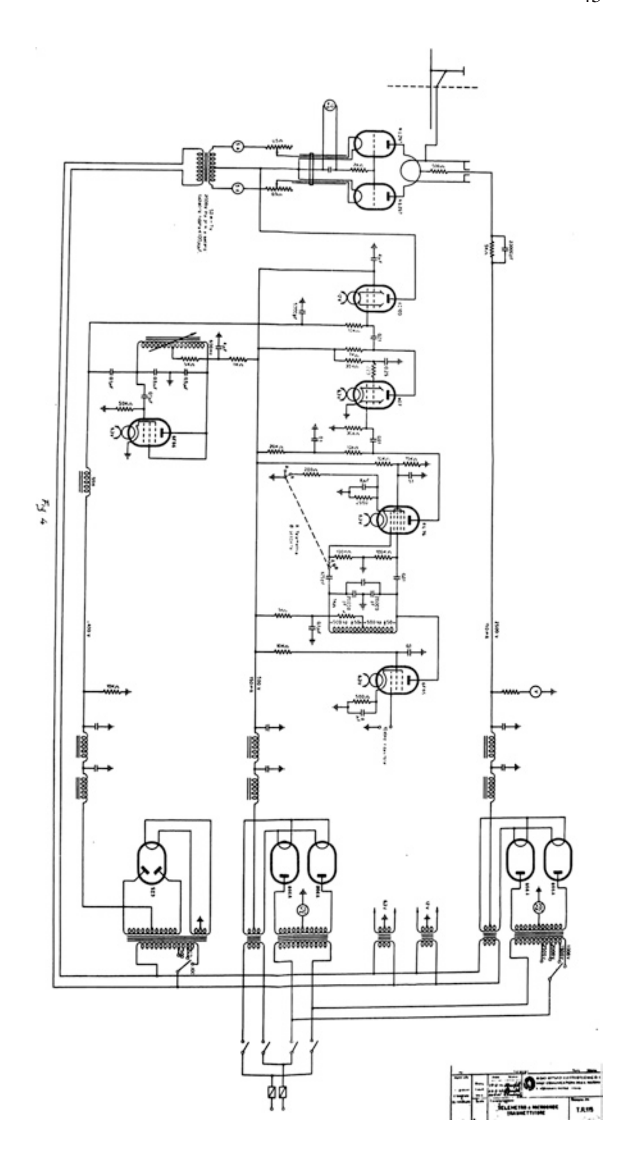


Fig. 2.29 Circuit scheme of the transmitter of the E.C.3-bis/ter

between the military authorities and the scientific ones on the other hand, was truly inadequate in relation to that times and to the value of events."

Perhaps at this point the reader may be curious to know if the *Gufo* was actually used and on board of which ships. Jumping, for now, the war context and the "wobble" of the decision-making process with regard to radar developments in Italy on 1939–1943, in Table 2.1 are listed, according to [Cer 95], the E.C.3-bis or



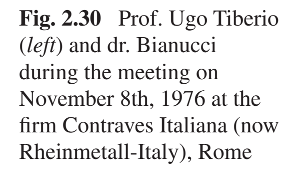


Fig. 2.30 Prof. Ugo Tiberio (*left*) and dr. Bianucci during the meeting on November 8th, 1976 at the firm Contraves Italiana (now Rheinmetall-Italy), Rome

E.C.3-ter radars installed on ships of the *Regia Marina* (a total amount of 15 sets on 14 ships) and operational until the end of hostilities.[24]

There are a very few images of Italian ships during the period 1941–1945 with radar on board, and in fact there were a few such ships and, see [Cer 95]. Moreover, sometimes a planned radar was not installed (and when installed, did not always work correctly). Some of these rare images, taken from [Bag 05], are shown in Figs. 2.31, 2.32, 2.33, 2.34, 2.35, 2.36, 2.37, 2.38 and 2.39, courtesy of captain Bagnasco.

[24]Among the vessels of Table 2.1 it is worth mentioning the battleship *Roma*, sunk on 9 September 1943 (i.e. the day after the armistice) by the Luftwaffe with a raid of two-engine Donier 217 k using radio controlled gliding bombs (forerunners of air—surface missiles) Ruhrstahl SD 1400 “Fritz X”. In that dramatic day Admiral Carlo Bergamini and most of his crew died [Amc 10]. The wreck of *Roma* was found at 1000 m depth, and 16 miles off the Asinara Island, on June 28th, 2012.

Table 2.1 Italian ships equipped with the national radar during the Second World War (adapted from [Cer 95], courtesy of MMI)

	Type of vessel	Name	Apparatus	Remark	Also cited in
1	Torpedo Boat	**Carini**	E.C.3-bis	**Experimental**—installed in April 1941	
2	Battleship	**Littorio**	E.C.3-bis	**Experimental**—installed between the end of 1941 and the spring of 1942	[Cas 79]
3	Battleship	**Littorio**	E.C.3-ter	Second apparatus installed in September 1942	[Sad 06], [Cas 79]
4	Destroyer	**Carabiniere**	E.C.3-ter	installed in January 1943	[Sad 06], [Cas 79]
5	Destroyer	**Leone Pancaldo**	E.C.3-ter	Installed in January 1943	[Sad 06], [Cas 79]
6	Destroyer	**Fuciliere**	E.C.3-ter	Installed in January 1943	[Sad 06], [Cas 79]
7	F 14 Tug	**Urania**	E.C.3-ter	Installed in April 1943- ship for trials and experiments	
8	Cruiser	**Scipione Africano**	E.C.3-ter	Installed in April 1943	[Cas 79], [Bag 78]
9	Battleship	**Vittorio Veneto**	E.C.3-ter	Installed in April 1943	[Cas 79]
10	Destroyer	**Ugolino Vivaldi**	E.C.3-ter	Installed in April/May 1943	[Bag 78]
11	Battleship	**Roma**	E.C.3-ter	Installed in June (August?) 1943	[Cas 79]
12	Cruiser	**Eugenio di Savoia**	E.C.3-ter	Installed in August 1943	[Cas 79], [Bag 78]
13	Destroyer	**Nicoloso da Recco**	E.C.3-ter	Installed in August 1943	[Bag 78]
14	Cruiser	**Raimondo Montecuccoli**	E.C.3-ter	Installed in August 1943	[Cas 79], [Bag 78]
15	Cruiser	**Attilio Regolo**	E.C.3-ter	Installed in August 1943	[Cas 79], [Bag 78]
16	Destroyer	**Velite**	EC.3-ter	Installed in August 1943	[Cas 79], [Bag 78]
17	Destroyer	**Dardo**	E.C.3-ter	Installed in August 1943	[Cas 79], [Bag 78]

The **bold** in the 4th column aims to distinguish between operational and experimental radar sets

Remark (a)*—According to [Bag 05], an E.C.3 prototype was installed on the battleship Littorio in August 1941 and sea trials were performed from November 1941; it was later (September 1942) replaced by E.C.3- ter Gufo, which had been tried for a long time at land and on board the tug boat Urania*

Remark (b)*—Immediately after the armistice, with the ships of the Italian Navy "cobelligeranti" with the Allies, the presence of German DeTe radar was correctly considered very dangerous given that the Germans knew perfectly their frequencies and various characteristics. Therefore, they were often replaced either with the Gufo or with the British radar Type 286 or Type 291*

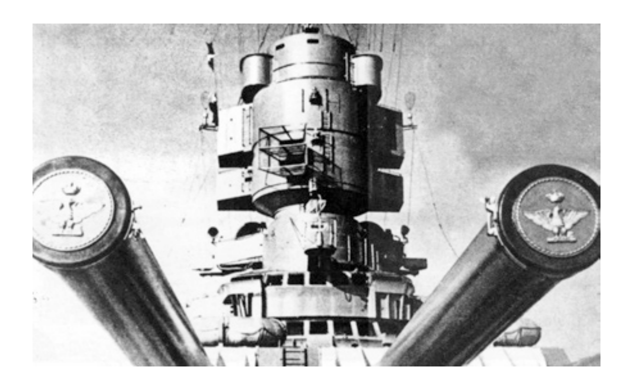


Fig. 2.31 The Battleship *Littorio* with the radar Gufo (1941)

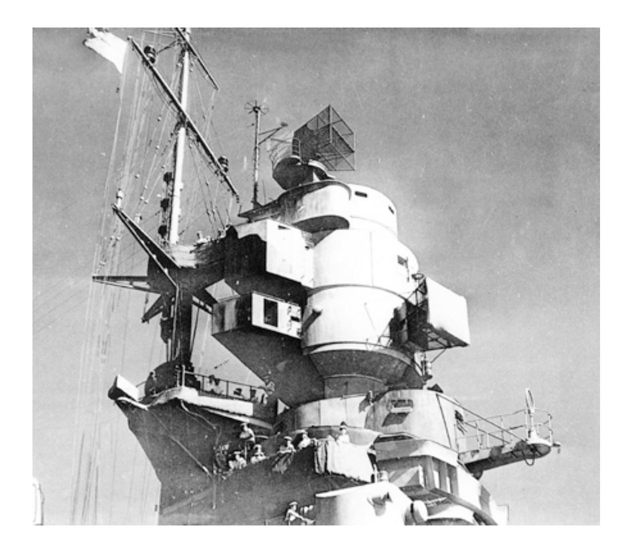
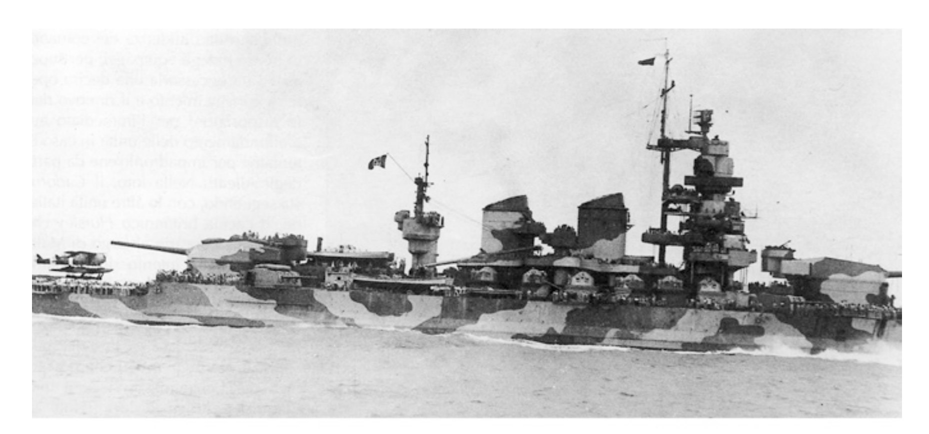


Fig. 2.32 The *upper part* of the tower of the battleship *Italia*, previously *Littorio*, on September 11th, 1943: on the *top*, the rotating antennas of E.C.3-ter "Gufo" on board from a few days and, on the telemetric turret, those, covered by a hood in canvas, of the previous "Gufo" apparatus



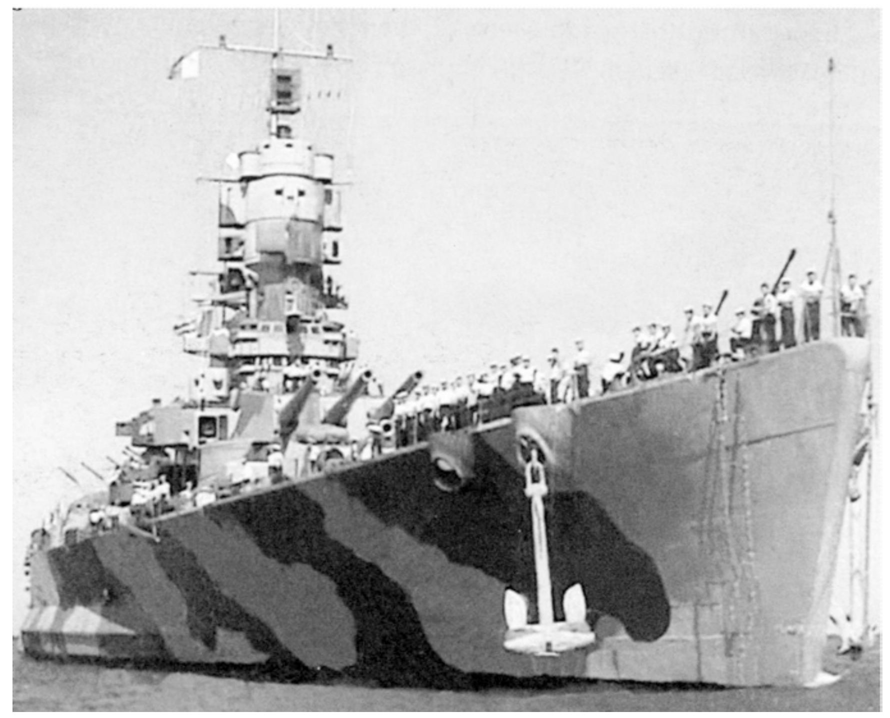


Fig. 2.33 The battleship *Littorio* with the *Gufo* radar (September 1943)

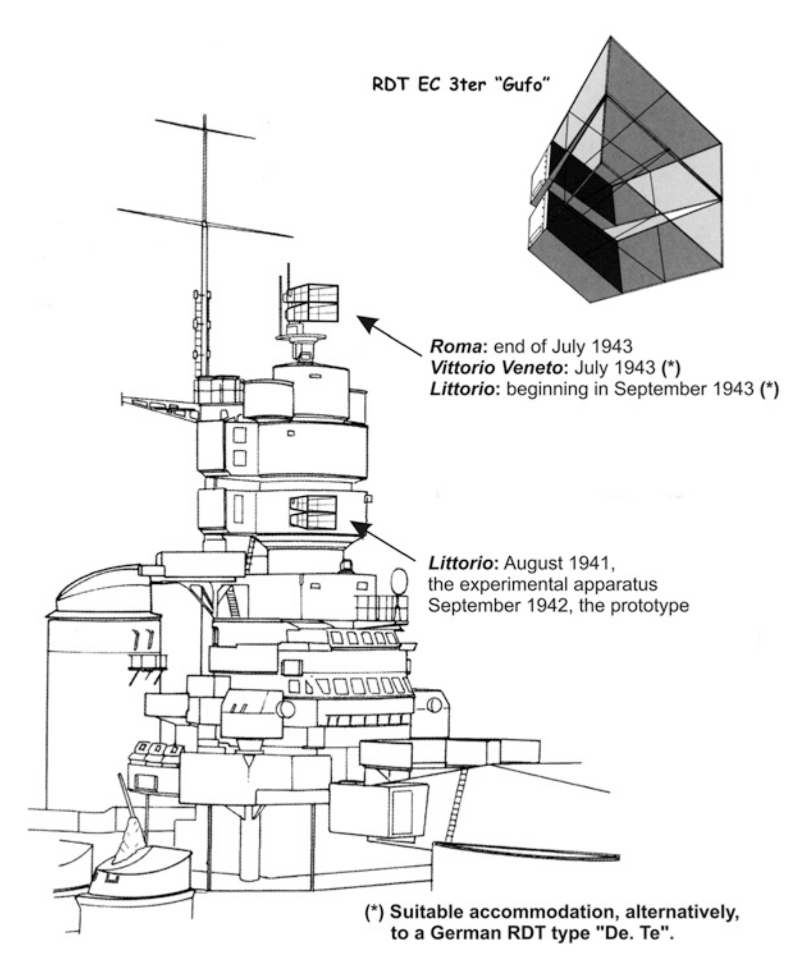


Fig. 2.34 Siting of the antennas of the E.C.3-ter "Gufo" and of the first experimental apparatus on board the battleships of "Littorio" class (Drawing by M. Brescia)



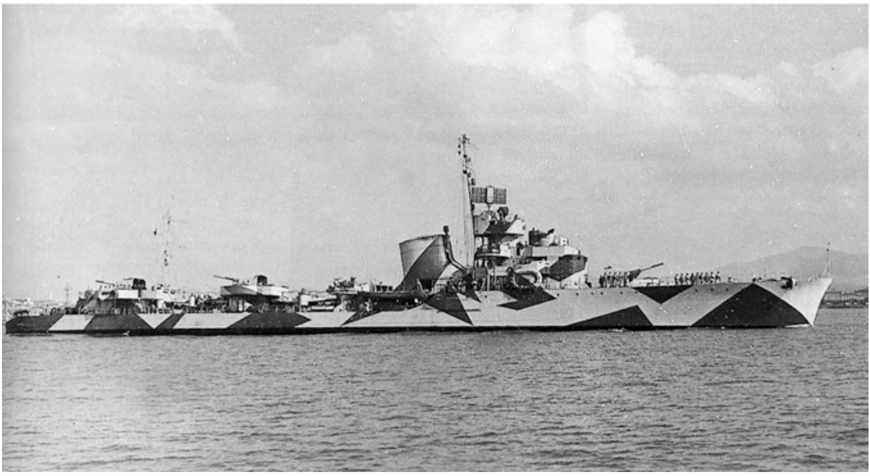


Fig. 2.35 The destroyer *Legionario*, first Italian unit equipped with an operational radar, photographed on May 18th, 1942. The antenna of the German radar "De Te" type FuMO 21/40 G is visible, after its installation in March 1942



Fig. 2.36 The Cruiser *Scipione Africano* with the radar *Gufo* (October 1943)

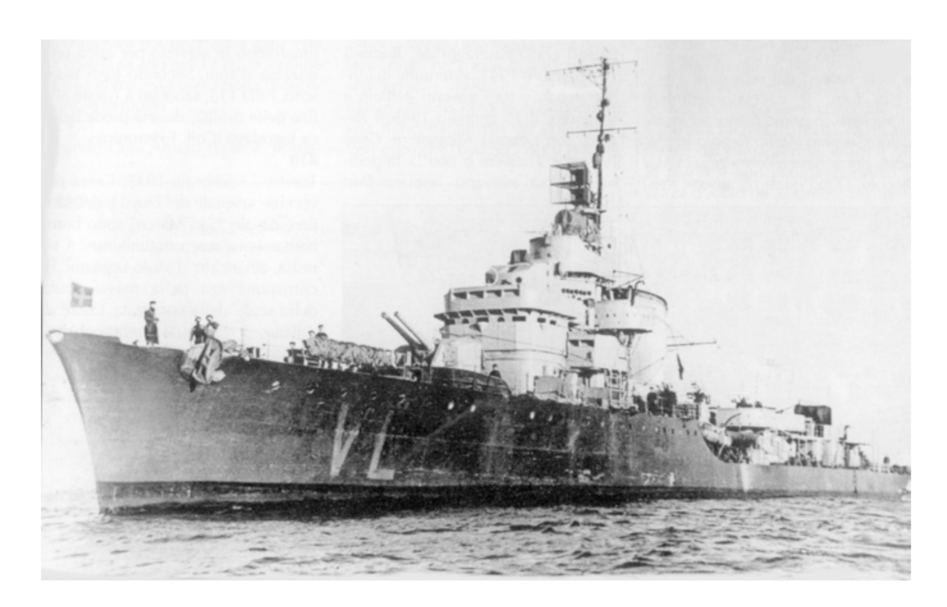


Fig. 2.37 The Destroyer *Velite* with the radar *Gufo* (1944/45)

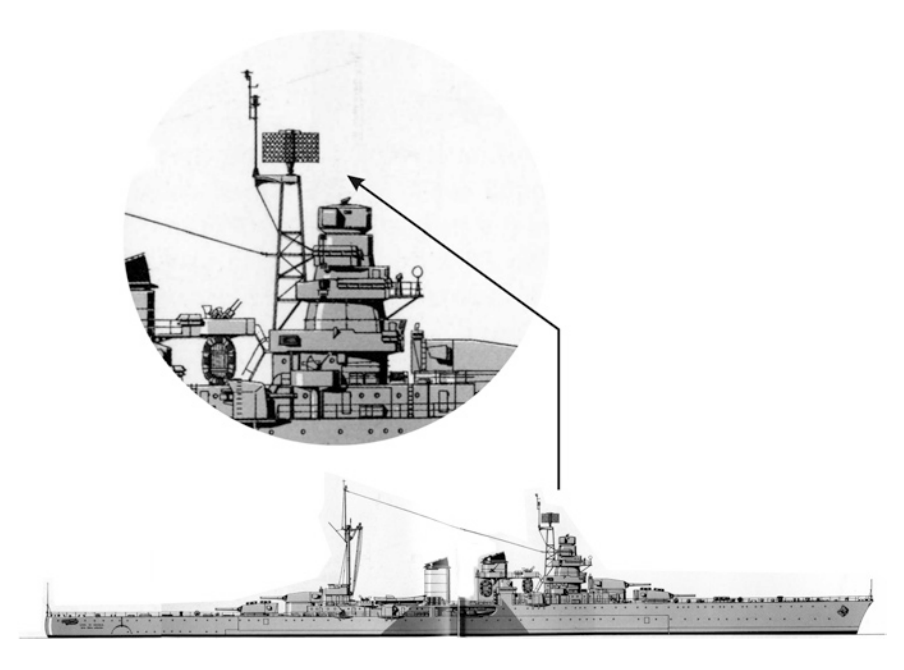


Fig. 2.38 The Cruiser *Luigi di Savoia Duca degli Abruzzi*, in 1944,with on board the German radar FuMO 21 G

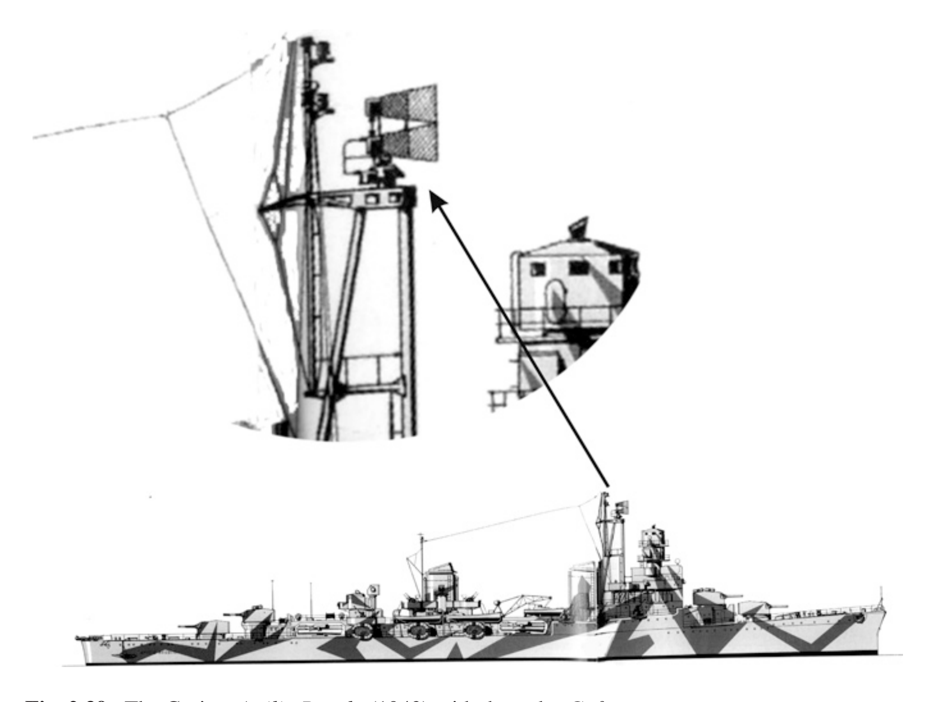


Fig. 2.39 The Cruiser *Attilio Regolo* (1943) with the radar *Gufo*



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